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Calculated and Measured S_{11} , S_{21} , and Group Delay for Simple Types of Coaxial and Rectangular Waveguide 2-Port Standards

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Calculated and Measured S_{11} , S_{21} , and Group Delay for Simple Types of Coaxial and Rectangular Waveguide 2-Port Standards

R. W. Beatty

Electromagnetics Division
Institute for Basic Standards
U.S. National Bureau of Standards
Boulder, Colorado 80302

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CALCULATED AND MEASURED S_{11} , S_{21} , AND GROUP DELAY FOR SIMPLE TYPES OF COAXIAL AND RECTANGULAR WAVEGUIDE 2-PORT STANDARDS

by
R.W. Beatty

ABSTRACT

Formulas, simple computer programs, graphs and tables are given to aid in the design and construction of 2-port standards for rectangular waveguide and coaxial line. Only standards consisting of reduced height waveguide, increased ODIC (outside diameter of inner conductor), or reduced IDOC (inside diameter of outer conductor) coaxial line are considered. Examples of the calculation of S_{11} , S_{21} and group delay, and their measurement with automatic network analyzers are given. Some of the important sources of error in the standards are discussed and design data are presented for specific standards.

Key words: Automatic network analyzers; coaxial; coaxial line step discontinuities; group delay; scattering coefficients; standards; 2-ports; waveguide; waveguide discontinuities.

1. INTRODUCTION

One can calculate the complex scattering coefficients S_{11} and S_{22} and the group delay τ_G of 2-port standards having simple geometries. These standards are useful for monitoring the performance of computer-controlled automatic network analyzers (A.N.A.) and for evaluating the accuracy of their measurements over broad frequency ranges. They may have additional uses in future developments.

There are many possible types of 2-port standards for which the above parameters may be calculated. Some examples of simple steps in diameters of inner and outer conductors of coaxial line and in the heights of rectangular waveguide are illustrated in figure 1(a-j). However, only three types are considered here [1]. They are the reduced IDOC (inside diameter of outer conductor) type of figure 1(b), the increased ODIC (outside diameter of inner conductor) of figure 1(c), and the reduced height (h_R) type of figure 1(j). These three types are chosen for their simplicity, ease of construction, and accuracy. For a given value of $|S_{11}|$ in the range $0 > |S_{11}| > 0.6$, the increased ODIC type of 2-port (used by Whinnery and Jamieson in 1944 [2]), has a somewhat greater sensitivity to dimensional error than the reduced IDOC type but is easier to make and more economical.

In use, the 2-port standards are inserted into a standard coaxial line or rectangular waveguide system at the output of an A.N.A. and their parameters measured over broad frequency ranges. One then compares the calculated and measured values in order to assess the performance and accuracy of the A.N.A.

In the following, formulas and simple computer programs are given, as well as some examples of calculated and measured results.

The accuracy of the calculated results are discussed. Means of estimating uncertainties due to the more important sources of error are described. Finally, design data is given for specific standards.

2. FORMULAS FOR CALCULATION

As shown in figure 2, an equivalent circuit for the above types of 2-port standards includes the normalized equivalent discontinuity susceptance $\frac{B}{Y_{OR}}$ and the attenuation α_R of the section of coaxial line or waveguide.

Using straightforward circuit analysis [3], one can derive the following formulas for S_{11} and S_{21} .

$$S_{11} = \frac{(1 + r - jbr)(1 - \frac{1}{r} - jb)e^{-2\gamma L} + (1 - r - jbr)(1 + \frac{1}{r} + jb)}{(1 - r + jbr)(1 - \frac{1}{r} - jb)e^{-2\gamma L} + (1 + r + jbr)(1 + \frac{1}{r} + jb)} \quad (1)$$

$$S_{21} = \frac{4e^{-\gamma L}}{(1 - r + jbr)(1 - \frac{1}{r} - jb)e^{-2\gamma L} + (1 + r + jbr)(1 + \frac{1}{r} + jb)} \quad (2)$$

where

$$r = \frac{Y_{OR}}{Y_{ON}}, \quad b = \frac{B}{Y_{OR}}, \quad \gamma = \alpha_R + j \frac{2\pi}{\lambda_G},$$

L = length of 2-port,

r = the ratio of the characteristic admittances of the 2-port's waveguide and of the external waveguide system,

and λ_G = waveguide wavelength.

Additional parameters used in calculating S_{11} and S_{21} for rectangular waveguide ($TE_{1,0}$ mode) and for coaxial line (TEM mode) are given in table 1.

The group delay parameter, τ_G , is defined in terms of ψ_{21} , the argument of S_{21} , as follows.

$$\tau_G = \frac{-d \psi_{21}}{d\omega} = \frac{-1}{2\pi} \frac{d \psi_{21}}{df}. \quad (3)$$

Alternately, we can write

$$\tau_G = \frac{-1}{2\pi} \lim_{\Delta f \rightarrow 0} \left(\frac{\Delta \psi_{21}}{\Delta f} \right), \quad (4)$$

where $\Delta \psi_{21}$ is the increment in ψ_{21} in degrees corresponding to a given increment Δf . For finite Δf ,

$$\tau_G \approx \frac{(\psi_{21})_L - (\psi_{21})_H}{360 (f_H - f_L)}, \quad (5)$$

where

$$f_H = f + 1/2 (\Delta f), \quad f_L = f - 1/2 (\Delta f), \text{ and } \Delta f \ll f.$$

We use eq (5) in calculating τ_G for 2-port standards, choosing $\Delta f < 0.1 f$. (One can test whether or not Δf has been chosen to be sufficiently small by recalculating with a still smaller Δf and comparing the differences in the τ_G 's obtained in the two calculations. Of course, if Δf is made too small, errors in calculation will result as one reaches the limits of computer capability. It is not usually difficult to tell when this happens.)

3. COMPUTER PROGRAMS

In order to make the results widely useful, simple computer programs have been developed in BASIC language. These have been designated as CS11, CS21, ICS11, and ICS21 for coaxial 2-ports, and WS11 and WS21 for rectangular waveguide. They are reproduced in the appendix to this note and are based on eqs (1), (2), and (5).

At the beginning of the programs the required input data and the calculated parameters are listed. Note that the computer programs WS11 and WS21 calculate the discontinuity susceptance from published formulas [7], but one must presently determine this separately in the case of coaxial lines¹ and insert the correct value into the program. Programs CS21 and WS21 calculate group delay τ_G as well as both magnitudes and arguments of S_{21} .

¹Calculation of coaxial line step capacitances is based upon the analysis of Whinnery, Jamieson, and Robbins, 1944 [8] and is aided by the work of Somlo, 1967 [9] and Jurkus, 1972 [10]. The step capacitances vary slowly with frequency up to the highest recommended frequencies for coaxial line and this frequency variation is presently neglected in computer programs CS11, CS21, ICS11, and ICS21. The step capacitances can also be determined by measuring the frequencies where $|S_{11}|$ is going through deep minima.

4. EXAMPLES OF CALCULATED AND MEASURED DATA

4.1 Reduced IDOC Coaxial 2-Port

(IDOC = 0.5135 inch, Length = 30.000 cm.)

The 2-port used in this example is shown in figure 3. Note that it is fitted with connectors which permit it to be inserted into a standard 50-ohm 9/16 inch (14 mm) coaxial system. Calculated values using programs CS11 and CS21 of S_{11} , S_{21} and τ_G for frequencies from 0.1 to 0.5 GHz are shown in figures 4 and 5. Measurements made on two automatic network analyzers "A" and "B" of different manufacturers are plotted with calculated data on figure 6 through 12, inclusive.

Figure 6 is a plot of S_{11} in polar coordinates.

Figure 7 shows return loss = $-20 \log_{10} |S_{11}|$ versus frequency.

Figure 8 shows ψ_{11} versus frequency.

Figure 9 is a polar plot of $-20 \log_{10} |S_{21}|$ and ψ_{21} at various frequencies.

Figure 10 shows $|S_{21}|$ versus frequency.

Figure 11 shows ψ_{21} versus frequency.

Figure 12 shows τ_G versus frequency.

4.2 Increased ODIC Coaxial 2-Port

(ODIC = 0.2651 inch, Length = 30.000 cm.)

The 2-port used in this example is shown in figure 13. Calculated values using programs ICS11 and ICS21 of S_{11} , S_{21} , and τ_G for frequencies from 0.1 to 0.5 GHz are shown in figures 14 and 15. Calculations and measured values are plotted in figures 16 to 22, inclusive.

4.3 Reduced Height Rectangular Waveguide 2-Port

(h_R = 0.0918 inch, Length = 0.4052 inch)

The 2-port used in this example² is shown in figure 23. Note that it has flanges for connection to a WR-90 (R-100) rectangular system. Calculated values using programs WS11 and WS21 of S_{11} , S_{21} , and τ_G for frequencies from 8 to 13 GHz are shown in figures 24 and 25. Measurements made on an automatic network analyzer are compared with calculated data in figures 26 to 31, inclusive.

²For the value of h_R in this example, measurements gave a value of discontinuity susceptance 4 percent higher than that calculated from [7]. Programs WS11 and WS21 were appropriately modified to include a factor of 1.04.

Figure 26 shows a plot of S_{11} and S_{21} in polar coordinates. Figure 27 shows return loss versus frequency. Figure 28 shows ψ_{11} versus frequency. Figure 29 shows attenuation versus frequency. Figure 30 shows ψ_{21} versus frequency. Figure 31 shows τ_G versus frequency.

4.4 Discussion

The examples of calculated and measured data are presented in various forms in order to show discrepancies between measurements and calculations. The purpose of showing the data is not to evaluate or compare automatic network analyzers. More data would be required in order to average out non-repeatable results due to operator errors, etc. The data shown does demonstrate the usefulness of 2-port standards in quickly checking all of the parameters measured by an A.N.A. over a broad frequency range.

In the examples shown, the length of the 2-port is less than a half-wavelength so that there can be no cyclical variations due to multiple reflections superimposed on the calculated curves. Any such variations observed in measured data must be due to error in measurement. Also, any sudden departures of measured data from the frequency variation of the calculated curves must be due to error in measurement. (This can be observed in figure 17, for example.)

In order to use 2-port standards to evaluate the accuracies of A.N.A. measurements, all of the errors in the standards should be carefully evaluated, and this has not been done. However, some measurements of $|S_{11}|$ have been made at fixed frequencies using tuned reflectometers with quarter-wave short-circuit standards. These measurements indicate that the curves of figure 33 represent the main source of error for $|S_{11}|$ values near the 2-port's quarter-wavelength frequencies.

The stability of the 2-port standards is of a high order so that non-repeatable results are due to non-repeatable connectors or waveguide joints, and to other insertion problems, operator error in calibrating the A.N.A., or A.N.A. instability. This is demonstrated in figure 7, where the results of two runs differ by about 0.2 decibel at 0.26 GHz. Non-repeatability effects have been observed which are much larger than this.

One should be cautious in drawing conclusions from the limited amount of data presented here. It does appear from figure 10 that A.N.A. "B" yields less scatter and more accurate values of $|S_{21}|$ over the frequency range 0.1 to 0.5 GHz and for $|S_{21}|$ near unity. Both "A" and "B" give accurate phase measurements of S_{21} . In the measurement of group delay, neither A.N.A. has sufficient resolution to show any variation with frequency. It would appear that "B" has less scatter than "A" for this

particular 2-port over the frequency range 0.1 to 0.5 GHz. The results of figure 31 show that for a different 2-port, measurements of group delay with A.N.A. "A" still exhibit considerable scatter, but show the correct frequency dependence of group delay.

5. DISCUSSION OF ERRORS

Although a complete investigation of all sources of error in S_{11} , S_{21} , and τ_G of the standards is desirable, it is not included in this report in order not to delay publication of useful information. The error in S_{11} due to uncertainty in the discontinuity capacitance is very small at frequencies for which the length of the 2-port is $\lambda_G/4$, but becomes large at $\lambda_G/2$ frequencies. Similarly, the value of S_{11} is insensitive to variations in the resistivity of the metal, except at and near $\lambda_G/2$ frequencies. The actual surface resistivity will vary with the fabrication process used. One can by trial and error make the calculated data fit the measured data at and near the $\lambda_G/2$ frequencies by choosing suitable values of resistivity and step capacitance and inserting these values in the appropriate computer programs CS11, ICS11, or WS11. The error in S_{21} due to uncertainty in the resistivity of the metal is also greatest at $\lambda_G/2$ frequencies. Thus, the best accuracy is expected to occur at and near $\lambda_G/4$ frequencies. It is felt that at present, the errors in calculated results are likely to be less than the errors in measured results at most frequencies, except near frequencies at which $|S_{11}|$ is going through deep minima.

Some of the sources of error are the following:

1. Dimensional tolerances in construction
 - a. uncertainty in reduced height or reduced IDOC,
 - b. uncertainty in width or in ODIC,
 - c. uncertainty in length.
2. Approximations in calculation of equivalent discontinuity susceptance
 - a. lack of rigor in theory,
 - b. errors in formulas,
 - c. errors in computer programs.
3. Faulty construction of standard
 - a. poor surface finish,
 - b. burrs,
 - c. lack of surface flatness or circularity.
4. Uncertainty in dissipative loss
 - a. attenuation,
 - b. losses at discontinuities,
 - c. losses at flanges or connectors.

5. Insertion errors

- a. misalignment
- b. system into which 2-port is inserted has non-standard dimensions and is different on one side of insertion point than the other.

A few of the major sources of uncertainty will be discussed as follows. A given uncertainty in the reduced height or reduced IDOC produces a corresponding uncertainty in the calculated value of $|S_{11}|$ at frequencies for which the length of the 2-port is an odd number of quarter wavelengths.

For small errors, we may use the following expressions.

For reduced height rectangular waveguide the fractional error in $|S_{11}|$ is

$$\frac{d|S_{11}|}{|S_{11}|} = - \frac{1 - |S_{11}|^2}{|S_{11}|} \cdot \frac{dh_R}{h_R} \quad (6)$$

This is derived by differentiating the relationship

$$S_{11} = - \frac{\left(\frac{h_N}{h_R}\right)^2 - 1}{\left(\frac{h_N}{h_R}\right)^2 + 1} \quad (7)$$

from [1], which holds closely at frequencies where L is an odd number of $\lambda_G/4$. For reduced IDOC coaxial line, the corresponding fractional error in $|S_{11}|$ is

$$\frac{d|S_{11}|}{|S_{11}|} = - \frac{1 - |S_{11}|^2}{|S_{11}|} \frac{d(Z_{OR})}{Z_{OR}}, \text{ or} \quad (8)$$

$$\frac{d|S_{11}|}{|S_{11}|} = - \frac{1 - |S_{11}|^2}{|S_{11}|} \cdot \frac{59.9392}{Z_{OR}} \cdot \frac{d(IDOC_R)}{IDOC_R} \quad (9)$$

Using eqs (6) and (9), data for the curves of figures 32 and 33 were obtained. The percent error in $|S_{11}|$ corresponding to a dimensional tolerance of 0.001 inch is shown in figure 32 for several standard sizes of rectangular waveguide and coaxial line. Figure 33 shows the effect of a smaller tolerance of 0.0001 inch.

One can easily determine the limits of uncertainty in S_{11} at other frequencies by perturbing the input data to computer programs CS11 and WS11, and observing the effect on uncertainties in S_{11} , S_{21} , and τ_G due to uncertainties in various input parameters with the exception of the inside width of the rectangular waveguide.

If the inside width of the rectangular waveguide 2-port is different than the width of the waveguide system into which the 2-port is inserted, unwanted reflections will be produced which can cause error. Evaluation of the uncertainty due to this error source can be accomplished using published formulas [7], but will not be discussed further in this note.

6. DESIGN INFORMATION

A design technique which has been used is to select values of $|S_{11}|$ that one would like to produce and then calculate the reduced height h_R , increased ODIC, or reduced IDOC required to obtain these values of $|S_{11}|$ at frequencies for which the length L of the 2-port is an odd number of $\lambda_G/4$, neglecting the effects of discontinuity susceptance.

Table II gives values of h_R corresponding to various values of $|S_{11}|$ for WR90 (R-100) rectangular waveguide. Table III gives values of increased ODIC and reduced IDOC for 9/16 inch (14 mm) coaxial 2-ports and table IV gives values of increased ODIC and reduced IDOC for 7 mm coaxial 2-ports. Table V gives approximate³ step capacitances versus $|S_{11}|$ for quarter wavelength 7 mm and 9/16 inch (14 mm) coaxial 2-ports using either increased ODIC or reduced IDOC.

The choice of length of the 2-port is arbitrary and some choices which have proven convenient are the following: for WR90 (R-100) rectangular waveguide, $L = 0.4052$ inch, $\sim\lambda_G/4$ @ 9.8 GHz, $L = 0.8104$ inch, $\sim\lambda_G/2$ @ 9.8 GHz. Figure 34 shows how $|S_{11}|$ varies across the frequency range for 2-ports having a length $L = 0.4052$ inch. A flatter frequency response may be obtained as shown in figure 35 by choosing $L = 0.3150$ inch (80 mm), $\sim\lambda_G/4$ @ 11.43067 GHz.

In order to facilitate design for still other standard sizes of rectangular waveguide or coaxial line, simple computer programs may be used. Programs IDOC and ODIC calculate the reduced IDOC and increased ODIC for quarter wavelength coaxial line 2-ports corresponding to chosen values of $|S_{11}|$. Program HR calculates values of reduced height h_R of quarter guide-wavelength rectangular waveguide 2-ports for chosen values of $|S_{11}|$. These programs appear in the appendix.

³The approximate values of step capacitance were obtained by interpolating in the tables of Somlo, 1967 [9], for $\tau = 2.3025$ which corresponds to $Z_0 = 50$ ohms. More accurate values will be available later both from measurements and from the computer programs of Somlo [9] and Jurkus [10].

In designing coaxial 2-ports to have many odd numbers of quarter-wave resonances, figure 36 is useful. At present, the calculated values of S_{11} are most accurate near these resonances and least accurate at frequencies where $|S_{11}|$ is minimum. Therefore, it might be advantageous to have a second 2-port standard for which $|S_{11}|$ is nearly maximum at frequencies where $|S_{11}|$ is minimum for the first 2-port standard.

7. CONCLUSION

Two-port standards in rectangular waveguide or coaxial line may be produced by reducing the height of a waveguide section, increasing the ODIC or reducing the IDOC of a coaxial line section. They may be designed to produce desired $|S_{11}|$ values at chosen frequencies. After design, the complex S_{11} and S_{21} and the group delay may readily be calculated over any desired frequency range. The accuracy of the calculated data at and near $\lambda_G/4$ frequencies is better than present measurement accuracy with many automatic network analyzers. At and near the $\lambda_G/2$ frequencies, the measured data may be assumed to be more accurate, and used to adjust the values of surface resistivity and shunt susceptance in the calculations. The 2-port standards are very stable and can be used for quickly checking performance and accuracy of automatic network analyzers over broad frequency ranges.

8. ACKNOWLEDGMENTS

The assistance of a number of people made this work possible. At NBS, George H. Fentress was the principal assistant in design, measurement, and presentation of results; Philip F. Biddle helped with mechanical design; William E. McNaney made accurate dimensional measurements and Fred F. Jeffers helped make measurements using an automatic network analyzer. Measurements using a different automatic network analyzer were kindly made by T.E. McKenzie, C.C. Gorss, and R.L. Moynihan of the General Radio Company, Bolton, Mass. Comments and suggestions were received from William E. Little and Clarence C. Cook of NBS, and Brent Palmer of the Hewlett-Packard Company.

9. APPENDIX

The following computer programs are given in the appendix; CS11, CS21, ICS11, ICS21, WS11, WS21, ODIC, IDOC, and HR. The purpose of each program is described in the REM statements, and use of the programs is intended to be evident to those having an elementary knowledge of computer BASIC language.

For reduced IDOC coaxial 2-port standards:

CS11 calculates return loss in decibels, magnitudes of S_{11} , and argument of S_{11} in degrees;

CS21 calculates attenuation in decibels, magnitude of S_{21} , argument of S_{21} in degrees and group delay time in nanoseconds.

For increased ODIC coaxial 2-port standards:

ICS11 calculates return loss in decibels, magnitude of S_{11} , and argument of S_{11} in degrees;

ICS21 calculates attenuation in decibels, magnitude of S_{21} , argument of S_{21} in degrees, and group delay time in nanoseconds.

For decreased height rectangular waveguide 2-port standards:

WS11 calculates return loss in decibels, magnitude of S_{11} , and argument of S_{11} in degrees;

WS21 calculates attenuation in decibels, magnitude of S_{21} , argument of S_{21} in degrees, and group delay time in nanoseconds.

ODIC: For given values of $|S_{11}|$, calculates return loss, VSWR, and the corresponding increased ODIC of $\lambda_G/4$ coaxial 2-port standards.

IDOC: For given values of $|S_{11}|$, calculates return loss, VSWR, and the corresponding reduced IDOC of $\lambda_G/4$ coaxial 2-port standards.

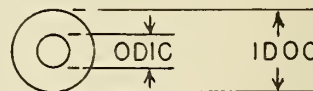
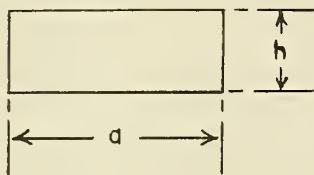
HR: For given values of $|S_{11}|$, calculates return loss, VSWR, and the corresponding reduced height of $\lambda_G/4$ rectangular waveguide 2-port standards.

10. REFERENCES

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- [5] Moreno, T., "Microwave Transmission Design Data" (Dover Publications, Inc., New York, New York, 1958), 63.
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- [7] Marcuvitz, N. (Editor), "Waveguide Handbook" (McGraw Hill Book Company, Inc., New York, New York, 1951), 296, 307.
- [8] Whinnery, J.R., H.W. Jamieson, and T.E. Robbins, "Coaxial-Line Discontinuities," *Proc. I.R.E.*, 32, no. 11, Nov. 1944, 695-709.
- [9] Somlo, P.I., "The Calculation of Coaxial Line Step Capacitances," *IEEE Trans. on MTT*, 15, no. 1, Jan. 1967, 48-53.
- [10] Jurkus, A., "Computation of Step Discontinuities in Coaxial Line," *IEEE Trans. on MTT*, 20, no. 10, Oct. 1972, 708-709.

TABLE I. ADDITIONAL PARAMETERS USED IN CALCULATING S_{11} , S_{21} , and τ_G of RECTANGULAR WAVEGUIDE and COAXIAL LINE 2-PORTS.

PARAMETER	RECTANGULAR WAVEGUIDE	COAXIAL LINE
r	$\frac{h_N}{h_R}$	$\frac{\ln \left(\frac{IDOC_N}{ODIC} \right)}{\ln \left(\frac{IDOC_R}{ODIC} \right)}$
λ_G inches	$\left[\left(\frac{f}{v} \right)^2 - \left(\frac{1}{a} \right)^2 \right]^{-1/2}$	$\frac{v}{f}$
$\frac{\alpha_{dB}}{ft.}$	$\frac{5.967 \sqrt{\rho} \left(\frac{1}{h_R} + \frac{\lambda^2}{2a^3} \right)}{\sqrt{\lambda} \sqrt{1 - \left(\frac{\lambda}{2a} \right)^2}}$ See [4]	$\frac{13.64 \sqrt{\epsilon_r} \left(\frac{\mu_{RI} \delta_I}{ODIC} + \frac{\mu_{RO} \delta_o}{IDOC_R} \right)}{\lambda_G \cdot \ln \left(\frac{IDOC_R}{ODIC} \right)}$ See [5]



- a = nominal inside width (inches) of rectangular waveguide.
 h_N = nominal inside height (inches) of rectangular waveguide system.
 h_R = reduced inside height (inches) of waveguide 2-port.
 $ODIC$ = outer diameter (inches) of inner conductor of coaxial line.
 $IDOC_N$ = nominal inside diameter (inches) of outer conductor of coaxial system.
 $IDOC_R$ = reduced inside diameter (inches) of inner conductor of 2-port.
 c = 2.997925×10^{10} cm/sec.
 f = frequency (Hz or cycles per second).
 ϵ_R = permittivity of air at 20°C, 760 mm pressure, 9° dewpoint temperature = 1.00064, see [6].
 v = $c/2.54\sqrt{\epsilon_R}$ inches/sec.
 λ = v/f inches.
 ρ = resistivity of waveguide or coaxial line conductors (ohm-cm).
 ρ_1 = resistivity of outer conductor (ohm-cm).
 ρ_2 = resistivity of inner conductor (ohm-cm).
 μ_{RO} = relative permeability of outer conductor.
 μ_{RI} = relative permeability of inner conductor.
 δ = skin depth (inches) of waveguide or coaxial line conductors. $[1/2\pi(2.54)] \sqrt{\rho/f}$ inches.
 δ_o = skin depth (inches) of outer conductor of 2-port.
 δ_I = skin depth (inches) of inner conductor of 2-port.

TABLE II. REDUCED HEIGHT h_R VERSUS MAGNITUDE OF S_{11} for QUARTER-GUIDE
WAVELENGTH WR-90 (R-100) RECTANGULAR WAVEGUIDE 2-PORTS.

MAGNITUDE OF S_{11}	RETURN LOSS IN DECIBELS	VSWR	REDUCED HEIGHT IN INCHES
0	Infinity	1	.4
.05	26.0206	1.10526	.380476
.1	20.	1.22222	.361814
.15	16.4782	1.35294	.343891
.2	13.9794	1.5	.326599
.25	12.0412	1.66667	.309839
.3	10.4576	1.85714	.29352
.35	9.11864	2.07692	.277555
.4	7.9588	2.33333	.261861
.45	6.93575	2.63636	.246353
.5	6.0206	3.	.23094
.55	5.19275	3.44444	.215526
.6	4.43698	4.	.2
.65	3.74173	4.71429	.184226
.7	3.09804	5.66667	.168034
.75	2.49878	7.	.151186
.8	1.9382	9.	.133333
.85	1.41162	12.3333	.113899
.9	.91515	19.	9.17663E-2
.95	.445528	39.	6.40513E-2

TABLE III. INCREASED ODIC and REDUCED IDOC VERSUS $|S_{11}|$ for 9/16 INCH (14 mm)
QUARTER-WAVELENGTH COAXIAL 2-PORTS.

MAGNITUDE OF S_{11}	RETURN LOSS, DECIBELS	VSWR	CHARACTERISTIC IMPEDANCE, IN OHMS	REDUCED IDOC IN INCHES	INCREASED ODIC IN INCHES
0	Infinity	1	50.0012	.5625	.24425
.05	26.0206	1.10526	47.5606	.540056	.2544
.1	20.	1.22222	45.2278	.519441	.264497
.15	16.4782	1.35294	42.9874	.500384	.27457
.2	13.9794	1.5	40.8258	.48266	.284653
.25	12.0412	1.66667	38.7308	.466081	.294778
.3	10.4576	1.85714	36.6909	.450486	.304983
.35	9.11864	2.07692	34.6953	.435735	.315308
.4	7.9588	2.33333	32.7335	.421704	.325799
.45	6.93575	2.63636	30.7948	.408283	.336508
.5	6.0206	3.	28.8682	.395368	.347501
.55	5.19275	3.44444	26.9414	.382861	.358853
.6	4.43698	4.	25.0006	.370662	.370662
.65	3.74173	4.71429	23.0289	.358668	.383058
.7	3.09804	5.66667	21.0047	.346758	.396215
.75	2.49878	7.	18.8987	.334785	.410384
.8	1.9382	9.	16.6671	.32255	.425951
.85	1.41162	12.3333	14.2377	.309738	.44357
.9	.91515	19.	11.4711	.295767	.464524
.95	.445528	39.	8.00661	.279156	.492164

TABLE IV. INCREASED ODIC and REDUCED IDOC VERSUS $|S_{11}|$ for 7 mm QUARTER-WAVELENGTH COAXIAL 2-PORTS.

MAGNITUDE OF S_{11}	RETURN LOSS, DECIBELS	VSWR	CHARACTERISTIC IMPEDANCE IN OHMS	REDUCED IDOC IN INCHES	INCREASED ODIC IN INCHES
0	Infinity	1	50.0522	.2759	.1197
.05	26.0206	1.10526	47.6092	.264881	.12468
.1	20.	1.22222	45.2739	.254759	.129633
.15	16.4782	1.35294	43.0312	.245403	.134575
.2	13.9794	1.5	40.8675	.236702	.139522
.25	12.0412	1.66667	38.7703	.228564	.14449
.3	10.4576	1.85714	36.7283	.220908	.149497
.35	9.11864	2.07692	34.7307	.213667	.154564
.4	7.9588	2.33333	32.7669	.20678	.159712
.45	6.93575	2.63636	30.8263	.200193	.164967
.5	6.0206	3.	28.8977	.193854	.170361
.55	5.19275	3.44444	26.9689	.187715	.175932
.6	4.43698	4.	25.0261	.181728	.181728
.65	3.74173	4.71429	23.0524	.175842	.187812
.7	3.09804	5.66667	21.0261	.169997	.19427
.75	2.49878	7.	18.918	.164122	.201224
.8	1.9382	9.	16.6841	.158118	.208865
.85	1.41162	12.3333	14.2522	.151831	.217513
.9	.91515	19.	11.4828	.144975	.227799
.95	.445528	39.	8.01477	.136825	.241368

TABLE V. APPROXIMATE STEP CAPACITANCES VERSUS $|S_{11}|$ FOR QUARTER WAVELENGTH
7 mm and 9/16 INCH (14 mm) COAXIAL 2-PORTS USING EITHER INCREASED ODIC
or DECREASED IDOC.

$ S_{11} $ for Quarter Wavelength 2-Port	STEP CAPACITANCE--femtofarads			
	7 mm		9/16 inch (14 mm)	
	Decreased IDOC	Increased ODIC	Decreased IDOC	Increased ODIC
0	0	0	0	0
.05	0.62	0.40	1.3	0.82
.1	1.9	1.2	3.8	2.56
.15	3.6	2.5	7.4	5.1
.2	5.7	4.1	11.7	8.3
.25	8.2	6.0	16.8	12.2
.3	11.	8.3	22.5	16.9
.35	14.	11	28.6	22.3
.4	17.3	14	35.3	28.6
.45	20.8	17.6	42	36
.5	24.6	21.7	50	44
.55	28.8	26.3	59	54
.6	33.3	31.8	68	65
.65	38	38	78	78
.7	44	46	89	93
.75	50	55	102	112
.8	58	67	118	136
.85	67	82	137	167
.9	80	104	163	213
.95	101	144	206	294

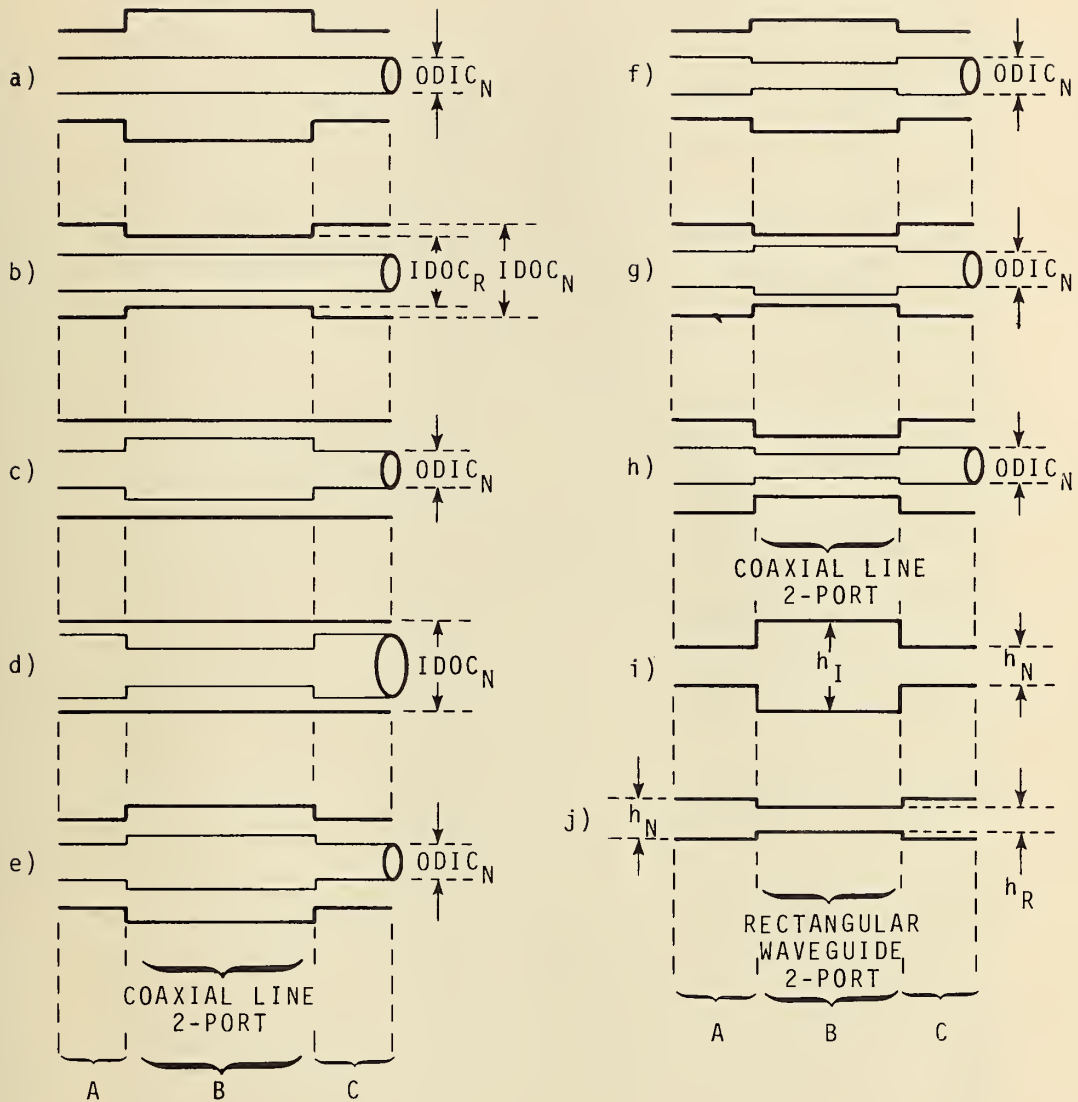


Figure 1. Examples of 2-port standards incorporating simple discontinuities in coaxial line (a-h) and rectangular waveguide (i-j). Regions A and C denote nominal coaxial cross-sectional dimensions specified by well-known standards, and region B denotes the 2-port sections having modified dimensions.

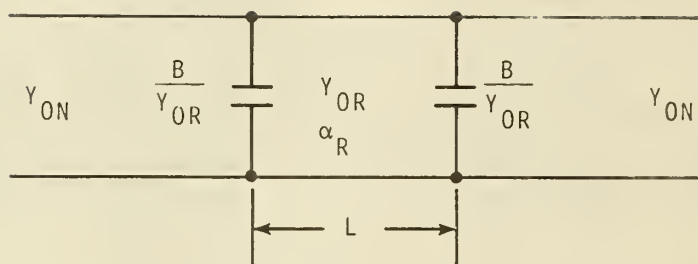


Figure 2. Equivalent circuit for dominant mode propagation in coaxial or rectangular waveguide 2-port standards of the types shown in figure 1. The characteristic admittances Y_{ON} and Y_{OR} are for the nominal standard waveguide and the 2-port section, respectively. The equivalent discontinuity susceptance is B , and the real part of the propagation constant is denoted by α_R .

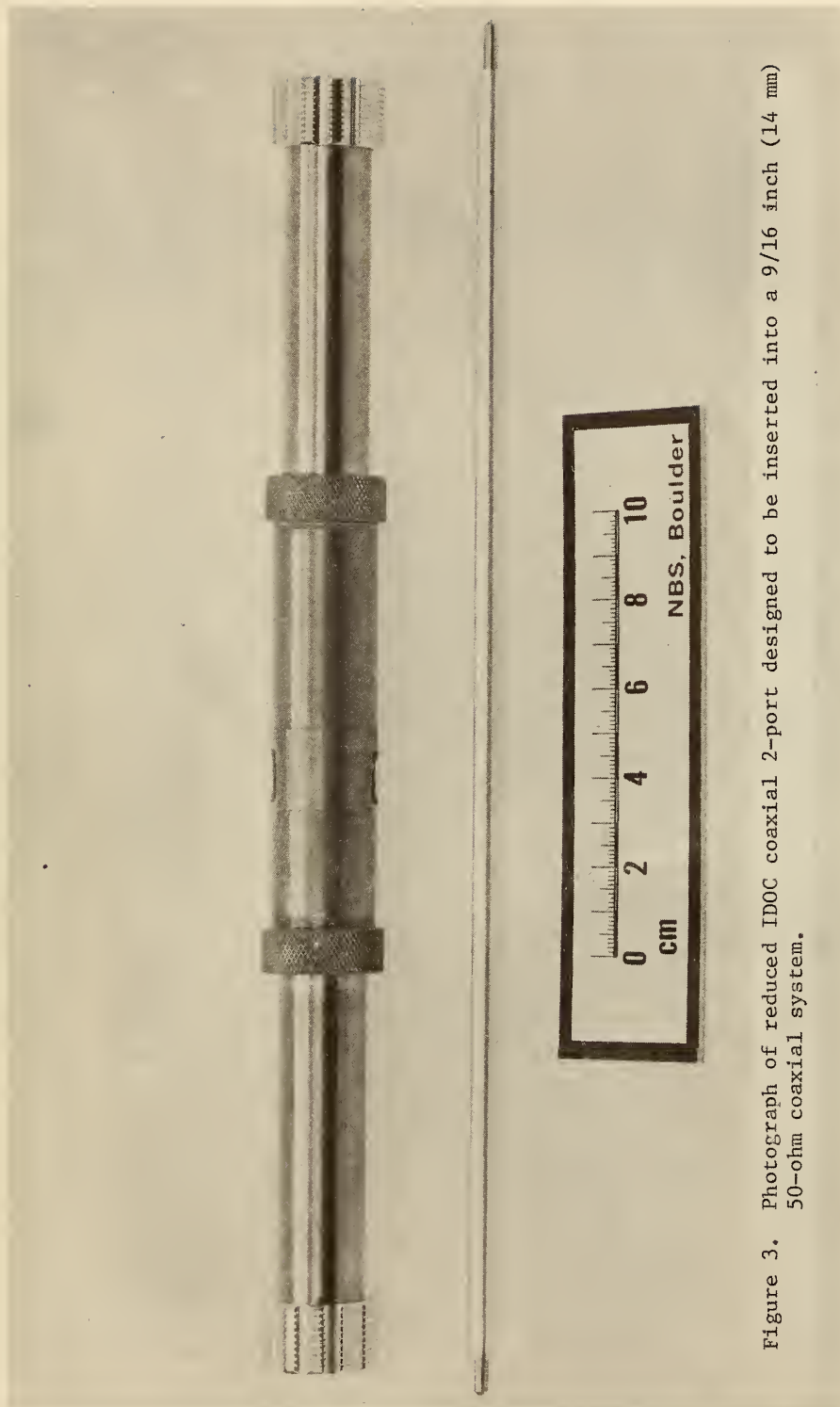


Figure 3. Photograph of reduced IDOC coaxial 2-port designed to be inserted into a 9/16 inch (14 mm) 50-ohm coaxial system.

CS11 08:56 06/04/74

FOR 9/16 INCH (14 MM) COAXIAL SYSTEM:

ODIC	.24425 INCHES
IDOC	.5625 INCHES
TEM-MODE CHARACTERISTIC IMPEDANCE	50.0012 OHMS

FOR 2-PORT:

ODIC	.24425 INCHES
IDOC	.5185 INCHES
LENGTH	11.811 INCHES
TEM-MODE CHARACTERISTIC IMPEDANCE	45.1191 OHMS
DISCONTINUITY CAPACITANCE	3.8E-15 FARADS
RELATIVE PERMITTIVITY OF AIR	1.00064
IC RESISTIVITY	.000002 OHM-CM.
OC RESISTIVITY	.000008 OHM-CM.

FREQUENCY GHZ	RETURN LOSS DECIBELS	MAG(S11)	ARG(S11) DEGREES
.1	24.368	6.04782E-2	233.74
.11	23.6677	.065556	230.137
.12	23.0523	7.03697E-2	226.536
.13	22.5103	7.49005E-2	222.937
.14	22.0331	7.91311E-2	219.34
.15	21.6137	8.30454E-2	215.746
.16	21.2468	8.66287E-2	212.153
.17	20.9279	8.98675E-2	208.563
.18	20.6537	9.27498E-2	204.974
.19	20.4213	.095265	201.387
.2	20.2285	9.74039E-2	197.802
.21	20.0734	9.91587E-2	194.219
.22	19.9547	.100523	190.637
.23	19.8714	.101492	187.055
.24	19.8227	.102062	183.475
.25	19.8083	.102231	179.894
.26	19.8281	.101999	176.314
.27	19.8822	.101366	172.734
.28	19.971	.100335	169.154
.29	20.0953	9.89088E-2	165.573
.3	20.2562	9.70936E-2	161.991
.31	20.4551	9.48956E-2	158.409
.32	20.6938	9.23228E-2	154.825
.33	20.9747	8.93848E-2	151.24
.34	21.3007	8.60924E-2	147.654
.35	21.6753	.082458	144.067
.36	22.1032	.078495	140.478
.37	22.5897	7.42187E-2	136.889
.38	23.1422	6.96453E-2	133.299
.39	23.7695	6.47923E-2	129.709
.4	24.4836	5.96787E-2	126.12
.41	25.3001	5.43245E-2	122.533
.42	26.2404	4.87506E-2	118.948
.43	27.3348	4.29793E-2	115.37
.44	28.6281	3.70335E-2	111.802
.45	30.1903	3.09373E-2	108.252
.46	32.1407	2.47152E-2	104.735
.47	34.7071	1.83926E-2	101.288
.48	38.4197	1.19954E-2	98.0246
.49	45.1127	5.55092E-3	95.5923
.5	60.4747	9.46813E-4	256.706

Figure 4. Computer printout of program CS11 for reduced IDOC coaxial 2-port.

CS21 09:18 06/04/74

FOR 9/16 INCH (14 MM) COAXIAL SYSTEM:

ODIC	.24425 INCHES
IDOC	.5625 INCHES
TEM-MODE CHARACTERISTIC IMPEDANCE	50.0012 OHMS

FOR 2-PORT:

ODIC	.24425 INCHES
IDOC	.5185 INCHES
LENGTH	11.811 INCHES
TEM-MODE CHARACTERISTIC IMPEDANCE	45.1191 OHMS
DISCONTINUITY CAPACITANCE	3.8E-15 FARADS
RELATIVE PERMITTIVITY OF AIR	1.00064
IC RESISTIVITY	.000002 OHM-CM.
OC RESISTIVITY	.000008 OHM-CM.

DELTA F FOR CALCULATION OF GROUP DELAY	.005 GHZ
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FREQUENCY GHZ	ATTENUATION DECIBELS	MAG(S21)	ARG(S21) DEGREES	GROUP DELAY NANOSECONDS
.1	2.40454E-2	.997235	-36.1865	1.00279
.11	2.72331E-2	.99687	-39.7954	1.00214
.12	3.04672E-2	.996498	-43.4019	1.00148
.13	3.37052E-2	.996127	-47.0061	1.00082
.14	.036902	.99576	-50.6078	1.00016
.15	4.00152E-2	.995404	-54.2072	.999523
.16	4.30018E-2	.995061	-57.8044	.99891
.17	4.58207E-2	.994739	-61.3994	.998335
.18	4.84335E-2	.994439	-64.9925	.997804
.19	5.08046E-2	.994168	-68.5837	.997328
.2	.052903	.993928	-72.1733	.996912
.21	5.46994E-2	.993722	-75.7615	.996565
.22	5.61722E-2	.993554	-79.3486	.996291
.23	5.73021E-2	.993425	-82.9349	.996093
.24	5.80768E-2	.993336	-86.5206	.995977
.25	5.84886E-2	.993289	269.894	.995942
.26	5.85352E-2	.993284	266.309	.99599
.27	5.82205E-2	.99332	262.723	.996119
.28	5.75534E-2	.993396	259.136	.996329
.29	5.65482E-2	.993511	255.549	.996614
.3	5.52252E-2	.993662	251.961	.996973
.31	5.36085E-2	.993847	248.371	.997399
.32	5.17276E-2	.994062	244.779	.997883
.33	4.96155E-2	.994304	241.186	.998422
.34	4.73094E-2	.994568	237.591	.999002
.35	4.48492E-2	.99485	233.993	.99962
.36	4.22769E-2	.995145	230.393	1.00026
.37	3.96372E-2	.995447	226.791	1.00092
.38	3.69755E-2	.995752	223.187	1.00158
.39	3.43365E-2	.996055	219.58	1.00224
.4	3.17664E-2	.996349	215.971	1.00288
.41	2.93091E-2	.996631	212.359	1.0035
.42	.027007	.996896	208.746	1.00407
.43	2.49004E-2	.997137	205.13	1.00461
.44	2.30264E-2	.997352	201.512	1.00508
.45	2.14177E-2	.997537	197.893	1.0055
.46	2.01037E-2	.997688	194.273	1.00585
.47	.019108	.997803	190.651	1.00612
.48	1.84505E-2	.997878	187.029	1.00632
.49	1.81443E-2	.997913	183.406	1.00643
.5	1.81976E-2	.997907	179.783	1.00646

Figure 5. Computer printout of program CS21 for reduced IDOC coaxial 2-port.

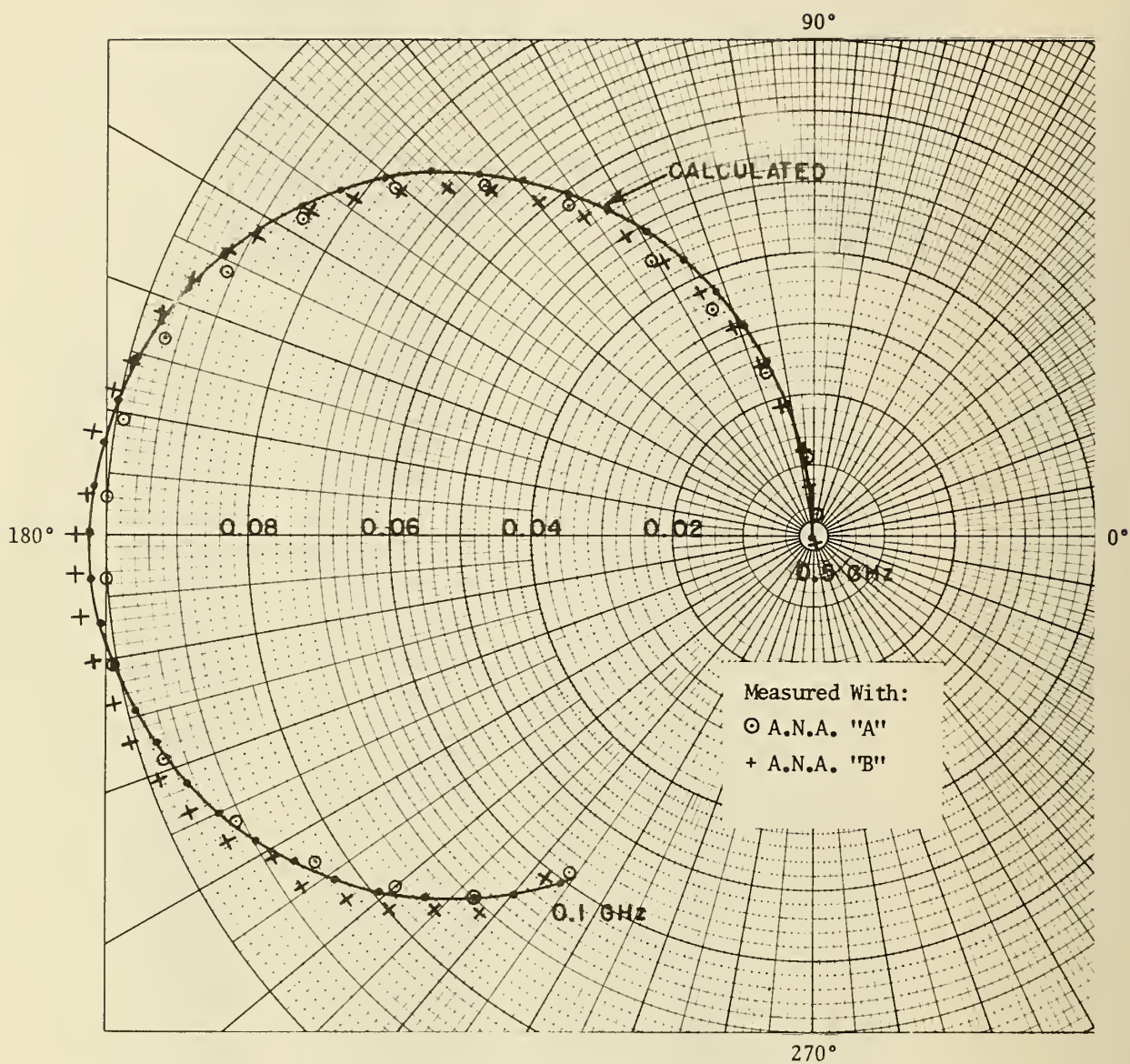


Figure 6. Polar plot of calculated and measured S_{11} of reduced IDOC coaxial 2-port for frequencies from 0.1 to 0.5 GHz.

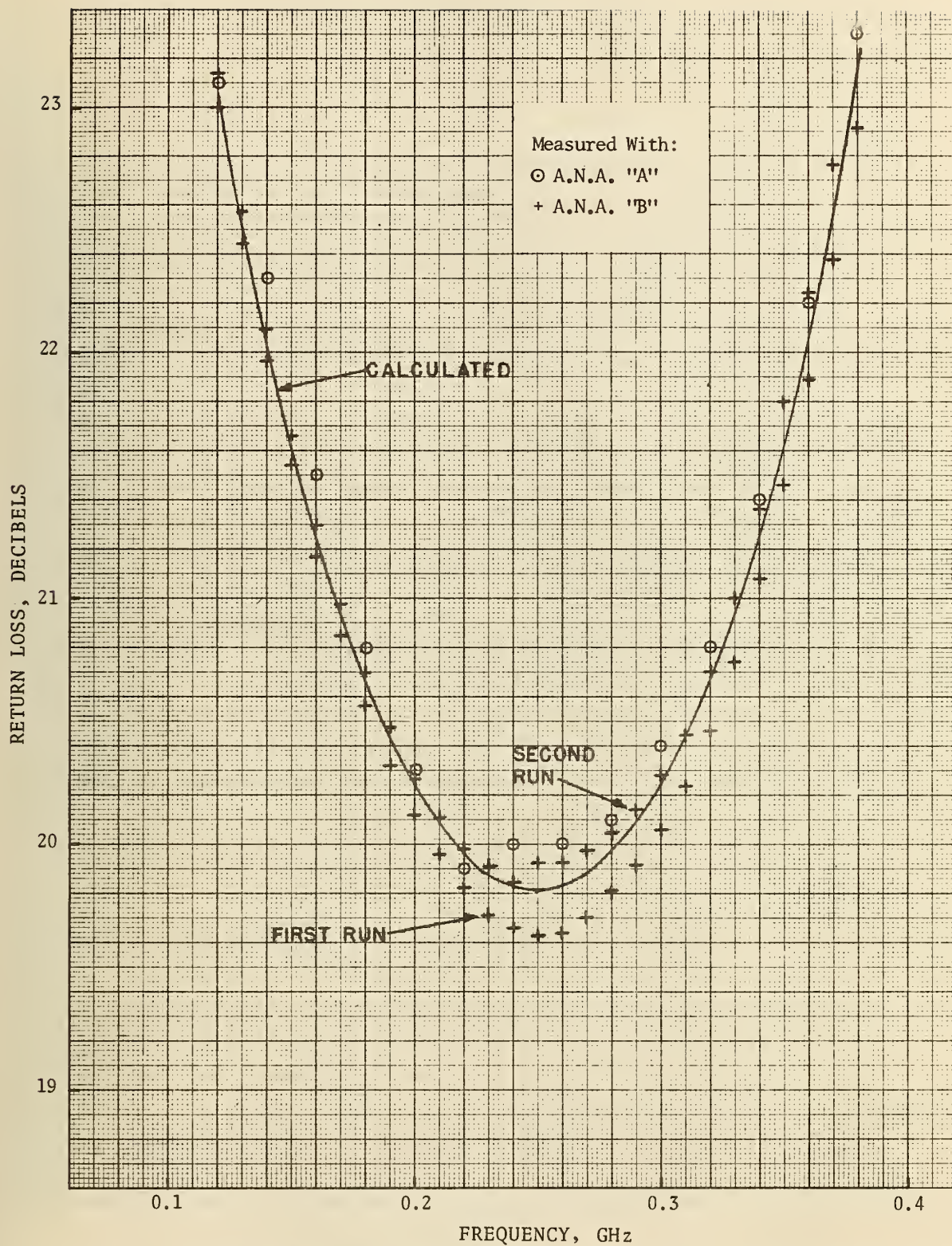


Figure 7. Calculated and measured return loss = $-20 \log_{10} |S_{11}|$ versus frequency for reduced IDOC coaxial 2-port.

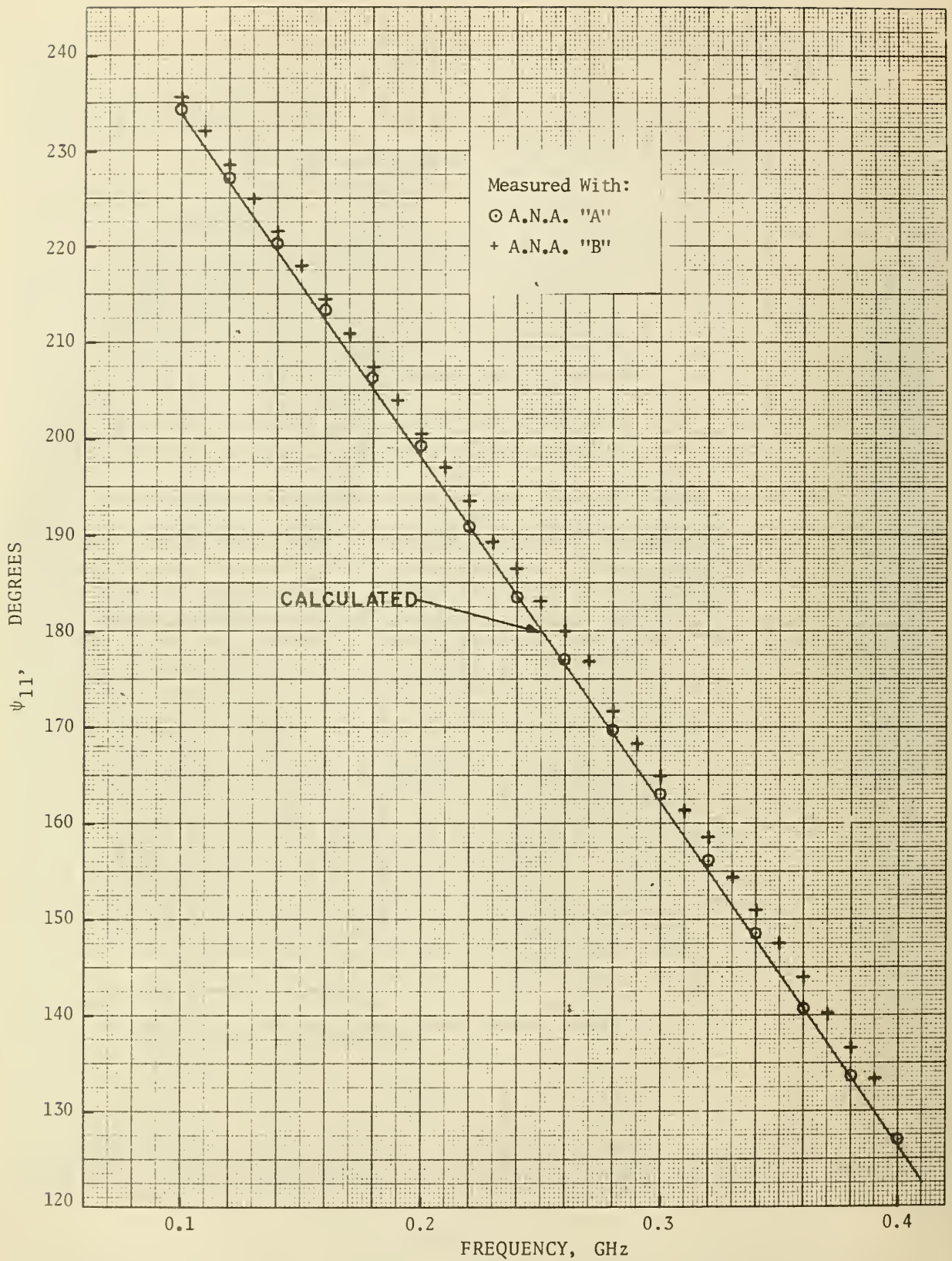


Figure 8. Calculated and measured $\arg(S_{11}) = \psi_{11}$ in degrees versus frequency for reduced IDOC coaxial 2-port.

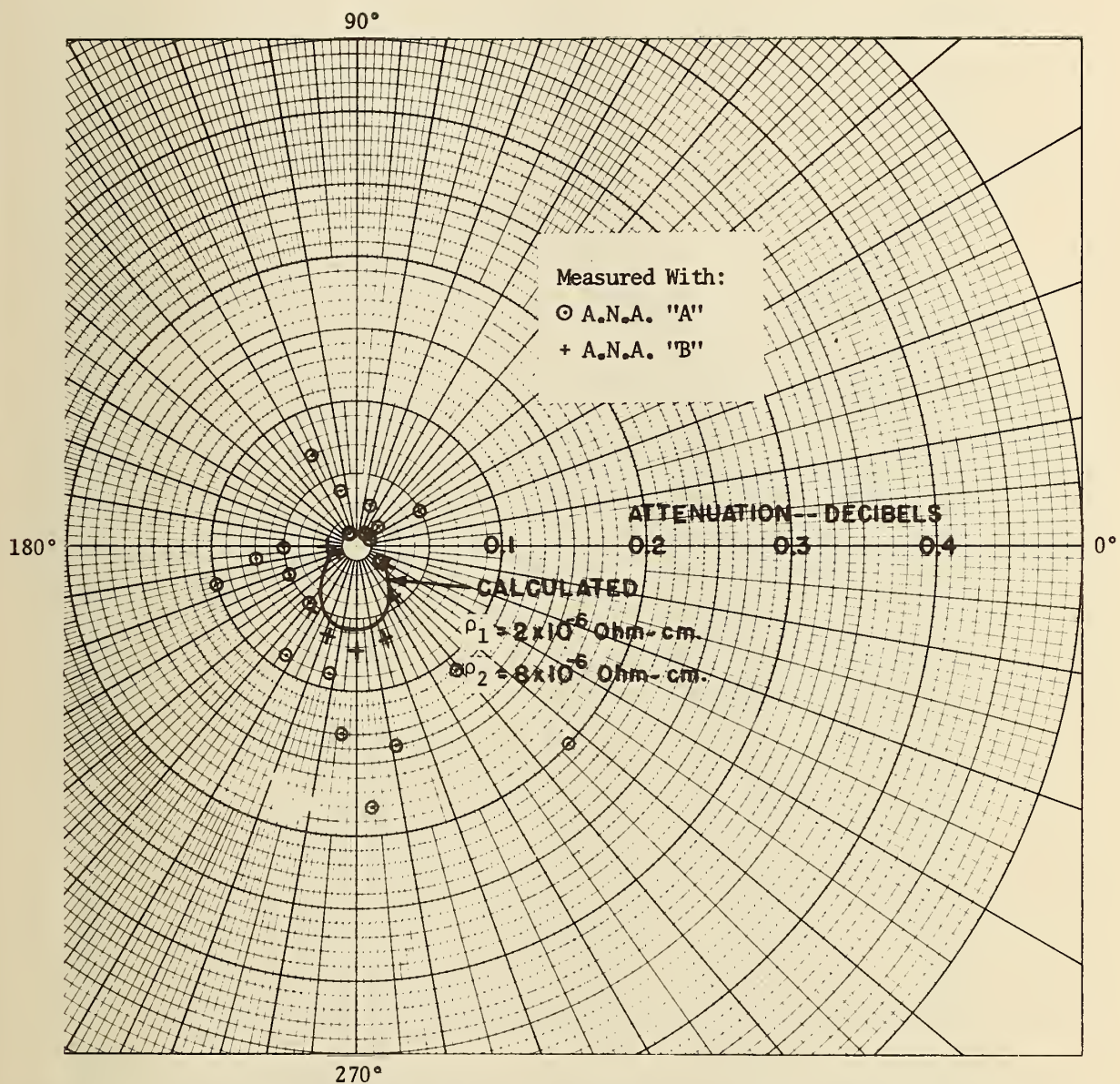


Figure 9. Polar plot of calculated and measured attenuation in decibels $= -20 \log_{10} |S_{21}|$ and $\arg(S_{21}) = \psi_{21}$ at frequencies from 0.1 to 0.5 GHz for reduced IDOC coaxial 2-port.

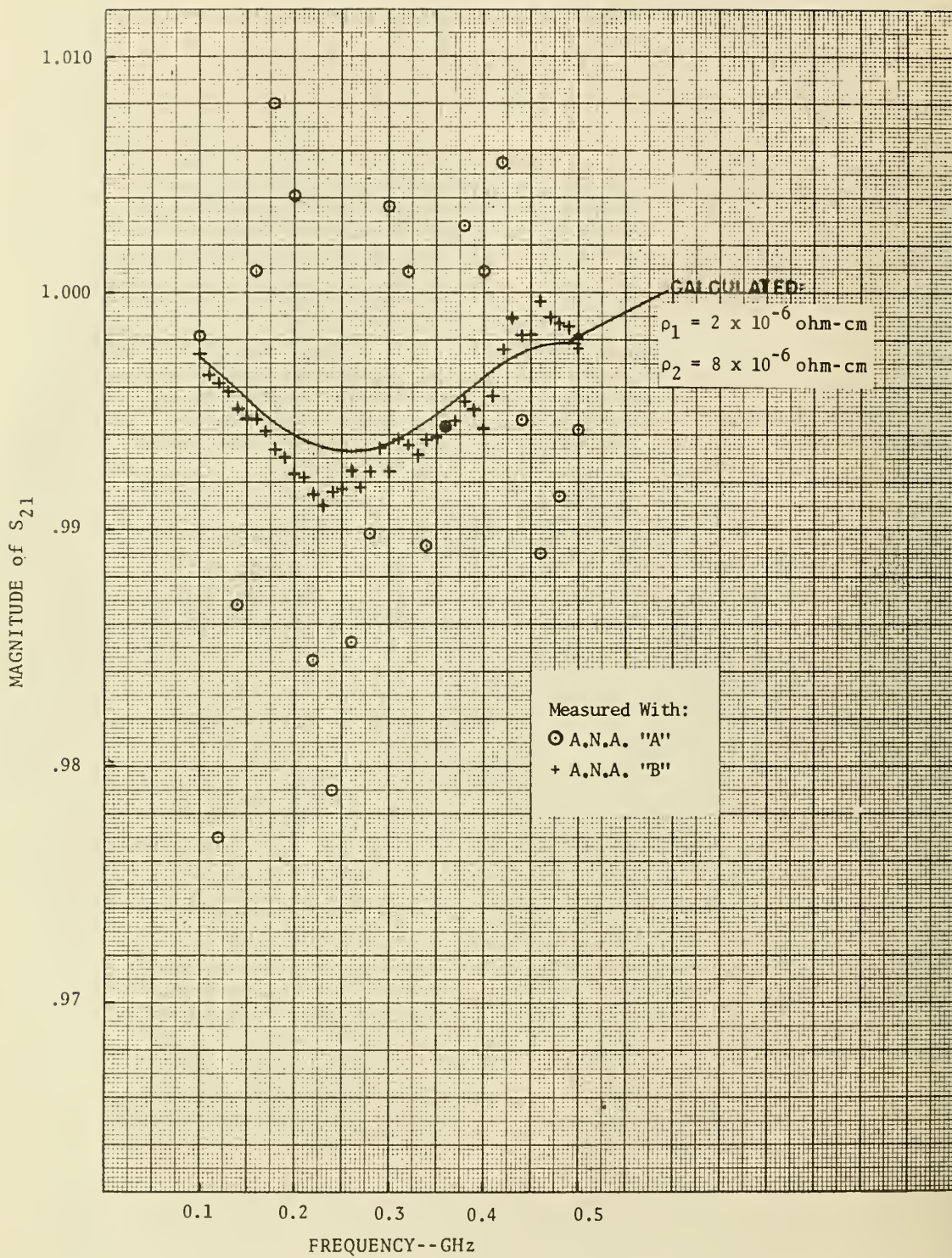


Figure 10. Calculated and measured $|S_{21}|$ versus frequency for reduced IDOC coaxial 2-port.

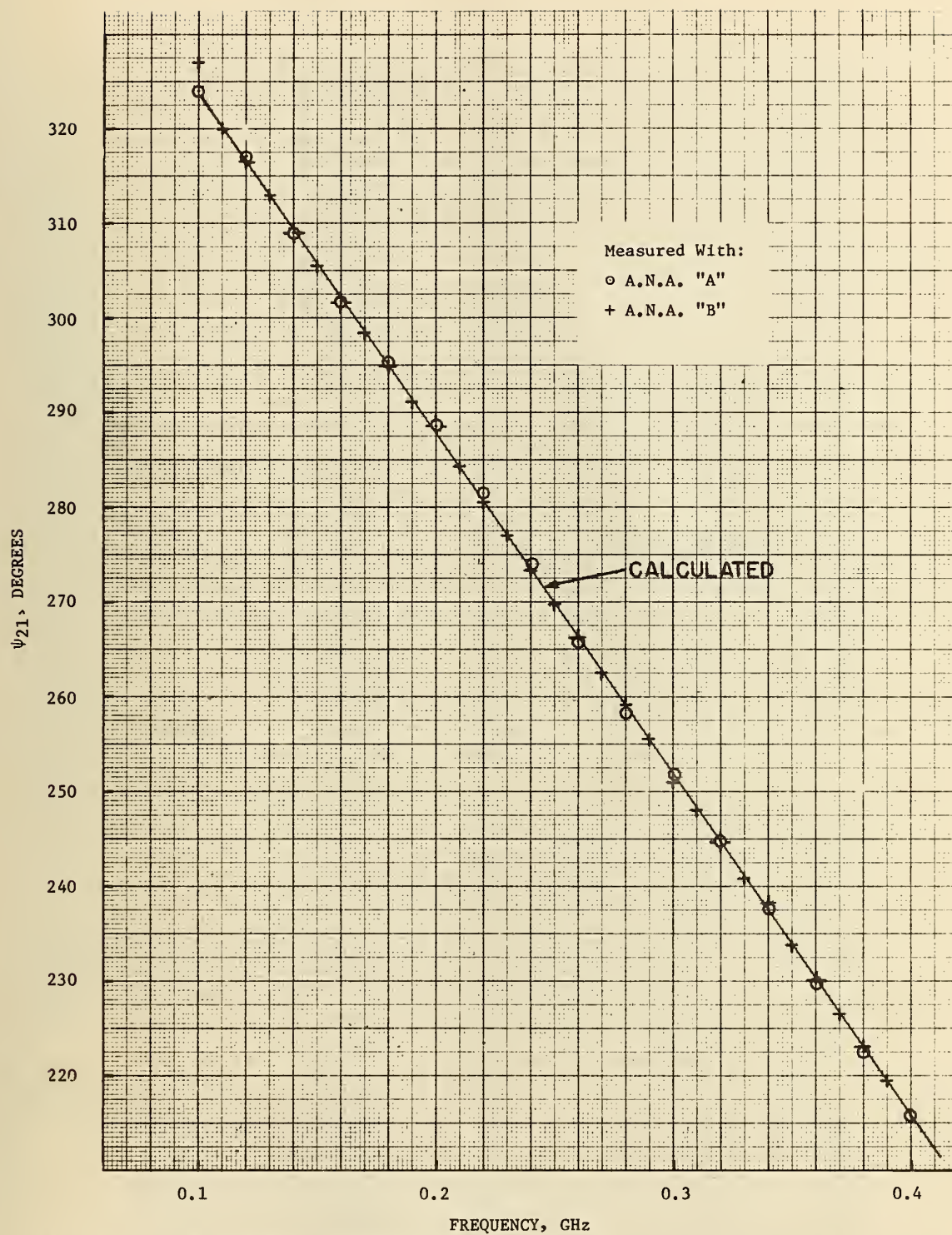


Figure 11. Calculated and measured $\arg(S_{21}) = \psi_{21}$ versus frequency for reduced IDOC coaxial 2-port.

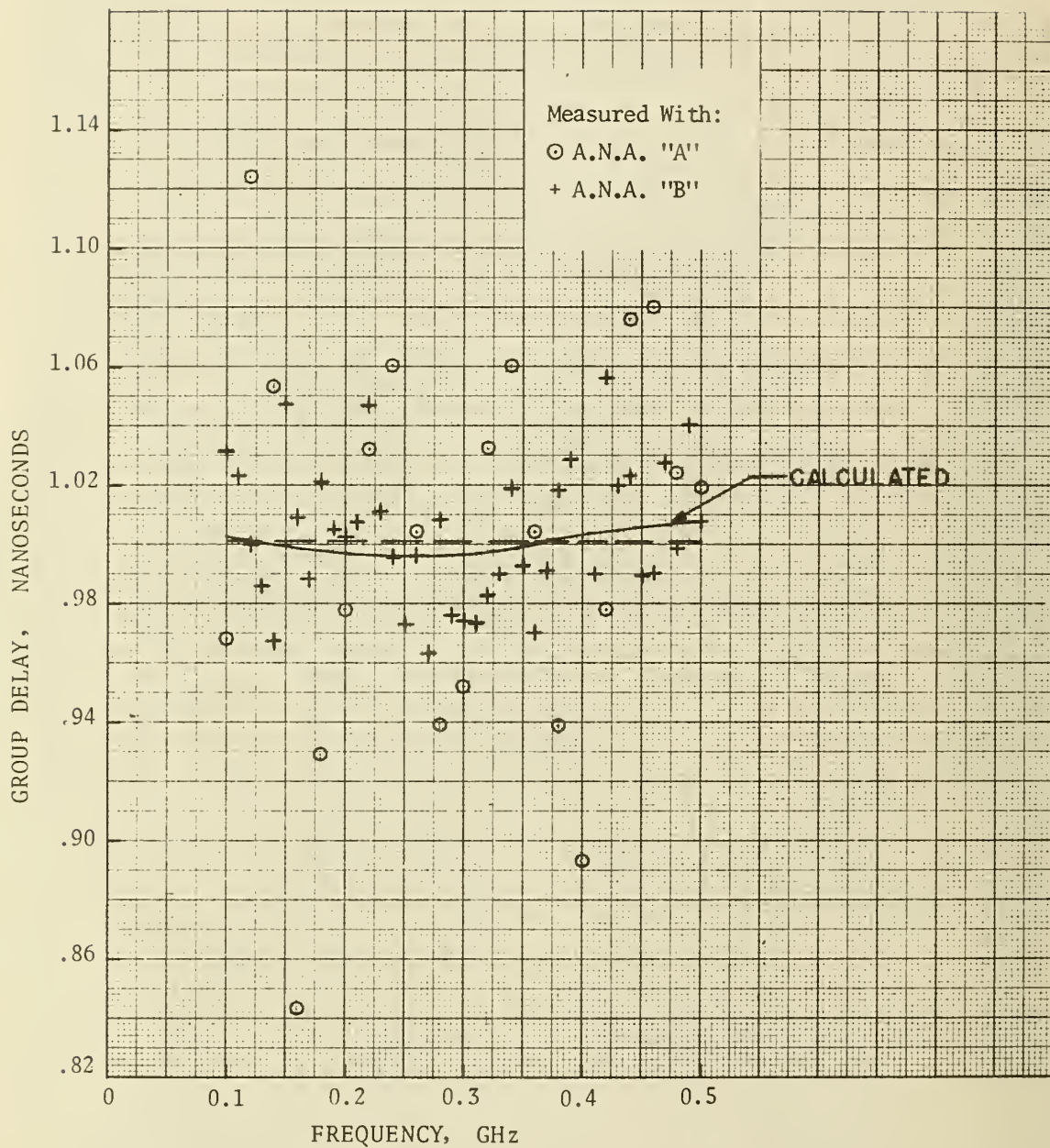


Figure 12. Calculated and measured group delay time versus frequency for reduced IDOC coaxial 2-port.

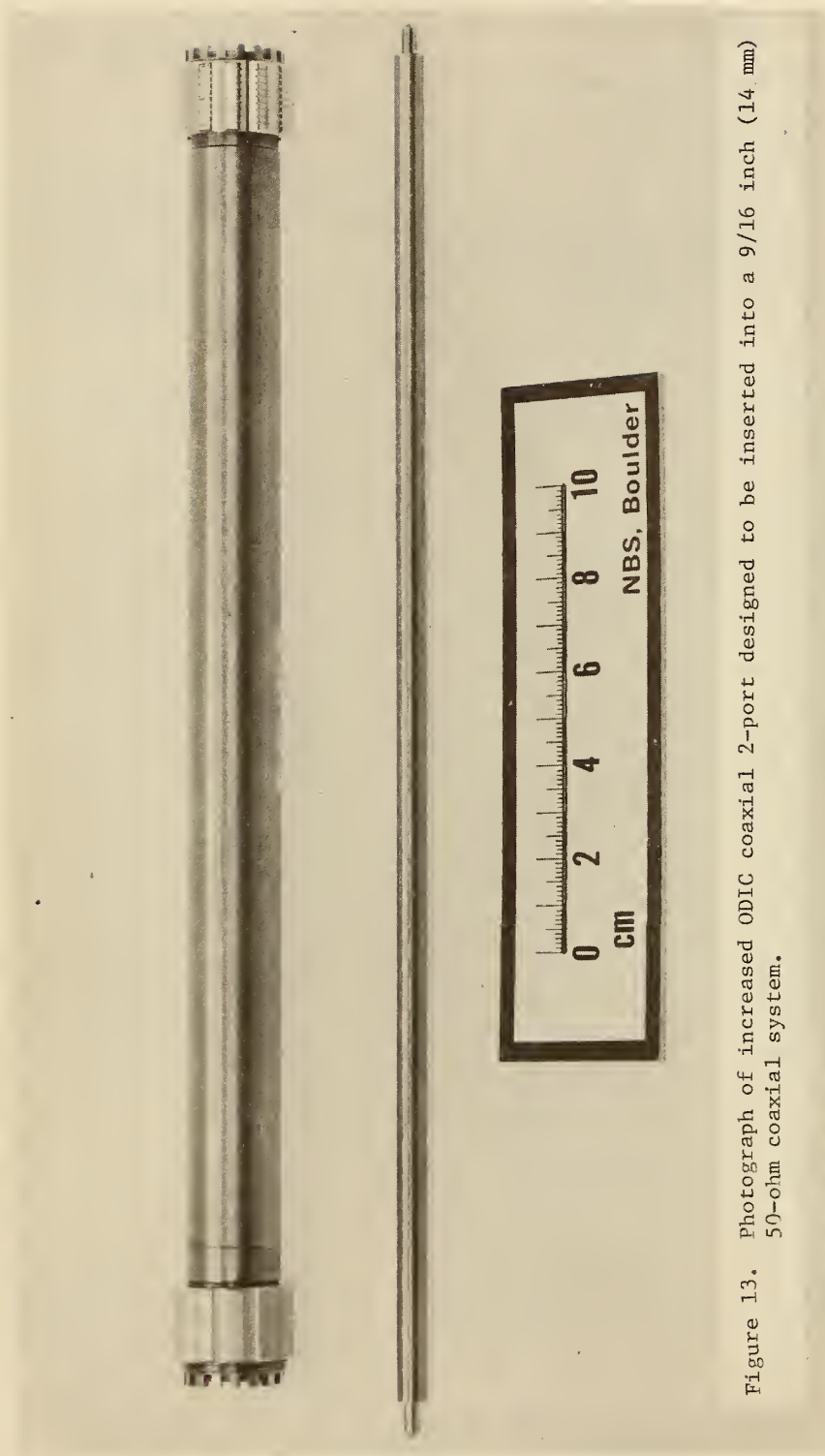


Figure 13. Photograph of increased ODIC coaxial 2-port designed to be inserted into a 9/16 inch (14 mm) 50-ohm coaxial system.

ICS11 08:30 06/07/74

FOR 9/16 INCH (14 MM) COAXIAL SYSTEM:

ODIC	.24425 INCHES
IDOC	.5625 INCHES
TEM-MODE CHARACTERISTIC IMPEDANCE	50.0012 OHMS

FOR 2-PORT:

ODIC	.2651 INCHES
IDOC	.5625 INCHES
LENGTH	11.811 INCHES
TEM-MODE CHARACTERISTIC IMPEDANCE	45.0913 OHMS
DISCONTINUITY CAPACITANCE	2.55531E-15 FARADS
RELATIVE PERMITTIVITY OF AIR	1.00064
IC RESISTIVITY	.000008 OHM-CM.
OC RESISTIVITY	.000008 OHM-CM.

FREQUENCY GHZ	RETURN LOSS DECIBELS	MAG(S11)	ARG(S11) DEGREES
.1	24.3239	6.07863E-2	233.712
.11	23.6236	6.58898E-2	230.111
.12	23.0082	7.07278E-2	226.512
.13	22.4662	7.52819E-2	222.916
.14	21.9889	7.95344E-2	219.321
.15	21.5695	8.34693E-2	215.728
.16	21.2025	8.70717E-2	212.138
.17	20.8835	9.03283E-2	208.55
.18	20.6092	.093227	204.963
.19	20.3766	9.57571E-2	201.379
.2	20.1835	9.79094E-2	197.796
.21	20.0282	.099676	194.215
.22	19.9092	.101051	190.635
.23	19.8256	.102028	187.056
.24	19.7766	.102606	183.477
.25	19.7618	.10278	179.9
.26	19.7811	.102552	176.322
.27	19.8347	.101922	172.745
.28	19.9229	.100891	169.167
.29	20.0466	9.94644E-2	165.589
.3	20.2068	9.76468E-2	162.011
.31	20.405	9.54448E-2	158.431
.32	20.6428	9.28664E-2	154.851
.33	20.9228	8.99211E-2	151.27
.34	21.2476	8.66199E-2	147.688
.35	21.6211	.082975	144.105
.36	22.0474	7.90002E-2	140.521
.37	22.5324	7.47103E-2	136.937
.38	23.0829	7.01219E-2	133.354
.39	23.7081	6.52524E-2	129.77
.4	24.4195	6.01209E-2	126.189
.41	25.2328	5.47472E-2	122.611
.42	26.1691	4.91527E-2	119.039
.43	27.2583	4.33594E-2	115.475
.44	28.5448	3.73904E-2	111.927
.45	30.0975	3.12698E-2	108.403
.46	32.0334	2.50223E-2	104.926
.47	34.5755	1.86734E-2	101.543
.48	38.2379	1.22492E-2	98.4103
.49	44.7642	5.77818E-3	96.3691
.5	62.0733	7.87655E-4	247.325

Figure 14. Computer printout of program ICS11 for increased ODIC coaxial 2-port.

ICS21 08:13 06/07/74

FOR 9/16 INCH (14 MM) COAXIAL SYSTEM:

ODIC	.24425 INCHES
IDOC	.5625 INCHES
TEM-MODE CHARACTERISTIC IMPEDANCE	50.0012 OHMS

FOR 2-PORT:

ODIC	.2651 INCHES
IDOC	.5625 INCHES
LENGTH	11.811 INCHES
TEM-MODE CHARACTERISTIC IMPEDANCE	45.0913 OHMS
DISCONTINUITY CAPACITANCE	2.55531E-15 FARADS
RELATIVE PERMITTIVITY OF AIR	1.00064
IC RESISTIVITY	.000008 OHM-CM.
OC RESISTIVITY	.000008 OHM-CM.

DELTA F FOR CALCULATION OF GROUP DELAY .005, GHZ

FREQUENCY GHZ	ATTENUATION DECIBELS	MAG(S21)	ARG(S21) DEGREES	GROUP DELAY NANOSECONDS
.1	2.74383E-2	.996846	-36.1859	1.00275
.11	3.08121E-2	.996459	-39.7947	1.0021
.12	3.42262E-2	.996067	-43.401	1.00143
.13	3.76386E-2	.995676	-47.005	1.00076
.14	4.10044E-2	.99529	-50.6065	1.0001
.15	4.42807E-2	.994915	-54.2057	.999451
.16	4.74251E-2	.994555	-57.8026	.998832
.17	5.03967E-2	.994215	-61.3973	.998251
.18	5.31572E-2	.993899	-64.99	.997714
.19	5.56706E-2	.993611	-68.5809	.997233
.2	5.79051E-2	.993356	-72.1702	.996813
.21	5.98333E-2	.993135	-75.758	.996462
.22	6.14317E-2	.992952	-79.3448	.996184
.23	6.26821E-2	.992809	-82.9306	.995984
.24	6.35715E-2	.992708	-86.5159	.995866
.25	6.40928E-2	.992648	269.899	.99583
.26	6.42432E-2	.992631	266.314	.995876
.27	6.40271E-2	.992656	262.729	.996006
.28	6.34527E-2	.992721	259.143	.996216
.29	6.25361E-2	.992826	255.556	.996504
.3	6.12962E-2	.992968	251.968	.996865
.31	5.97578E-2	.993144	248.378	.997293
.32	5.79507E-2	.99335	244.787	.997781
.33	5.59086E-2	.993584	241.194	.998324
.34	5.36687E-2	.99384	237.599	.99891
.35	.051271	.994115	234.002	.999532
.36	4.87585E-2	.994402	230.403	1.00018
.37	4.61758E-2	.994698	226.801	1.00084
.38	4.35682E-2	.994997	223.197	1.00151
.39	4.09822E-2	.995293	219.59	1.00218
.4	3.84636E-2	.995581	215.981	1.00282
.41	3.60566E-2	.995857	212.37	1.00344
.42	.033805	.996116	208.756	1.00403
.43	3.17485E-2	.996351	205.141	1.00457
.44	2.99247E-2	.996561	201.523	1.00505
.45	2.83672E-2	.996739	197.904	1.00548
.46	2.71055E-2	.996894	194.284	1.00583
.47	2.61641E-2	.996992	190.662	1.00611
.48	2.55623E-2	.997061	187.04	1.00631
.49	2.53142E-2	.99709	183.417	1.00642
.5	.025428	.997077	179.794	1.00646

Figure 15. Computer printout of program ICS21 for increased ODIC coaxial 2-port.

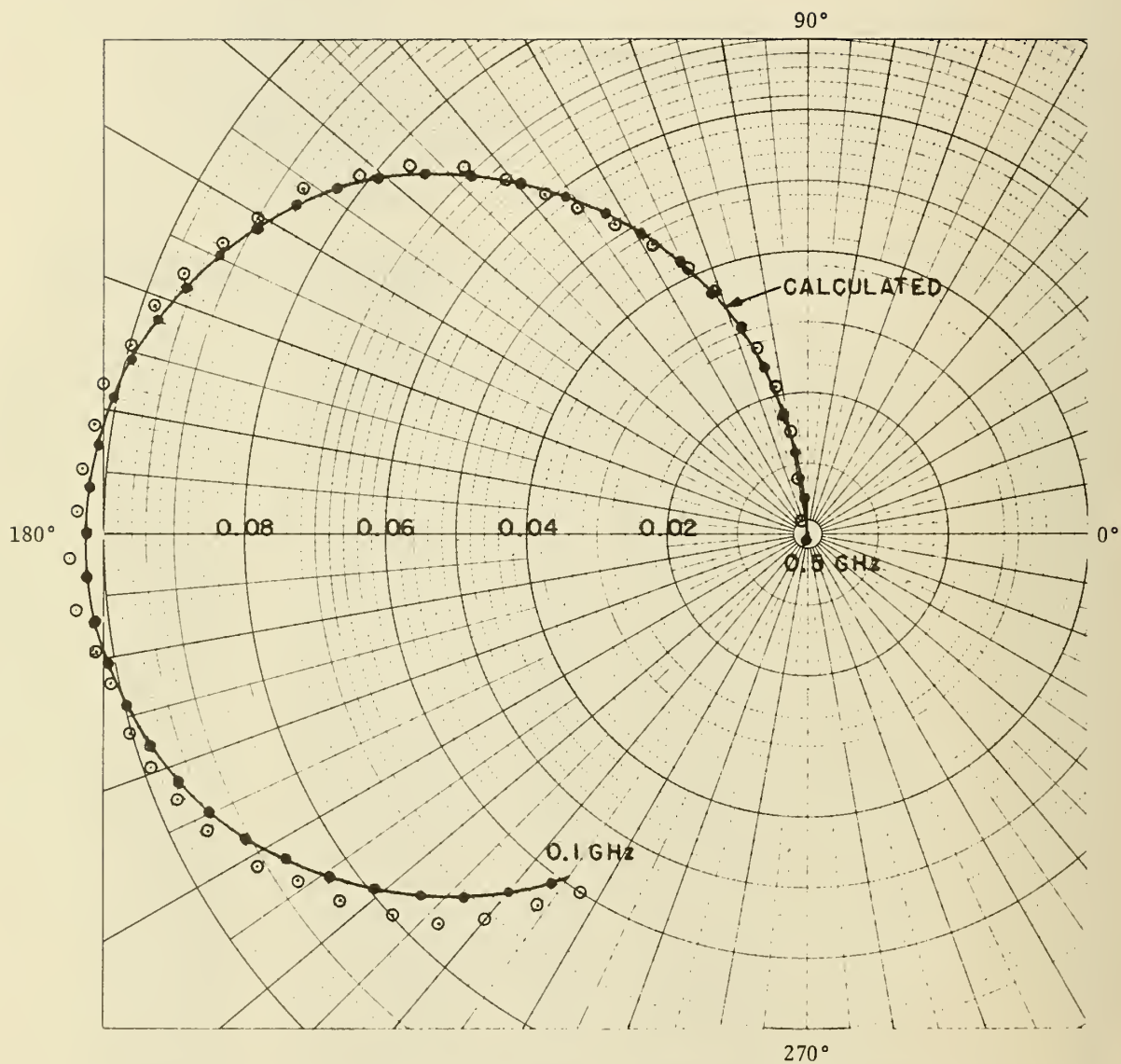


Figure 16. Polar plot of calculated and measured S_{11} of increased ODIC coaxial 2-port for frequencies from 0.1 to 0.5 GHz.

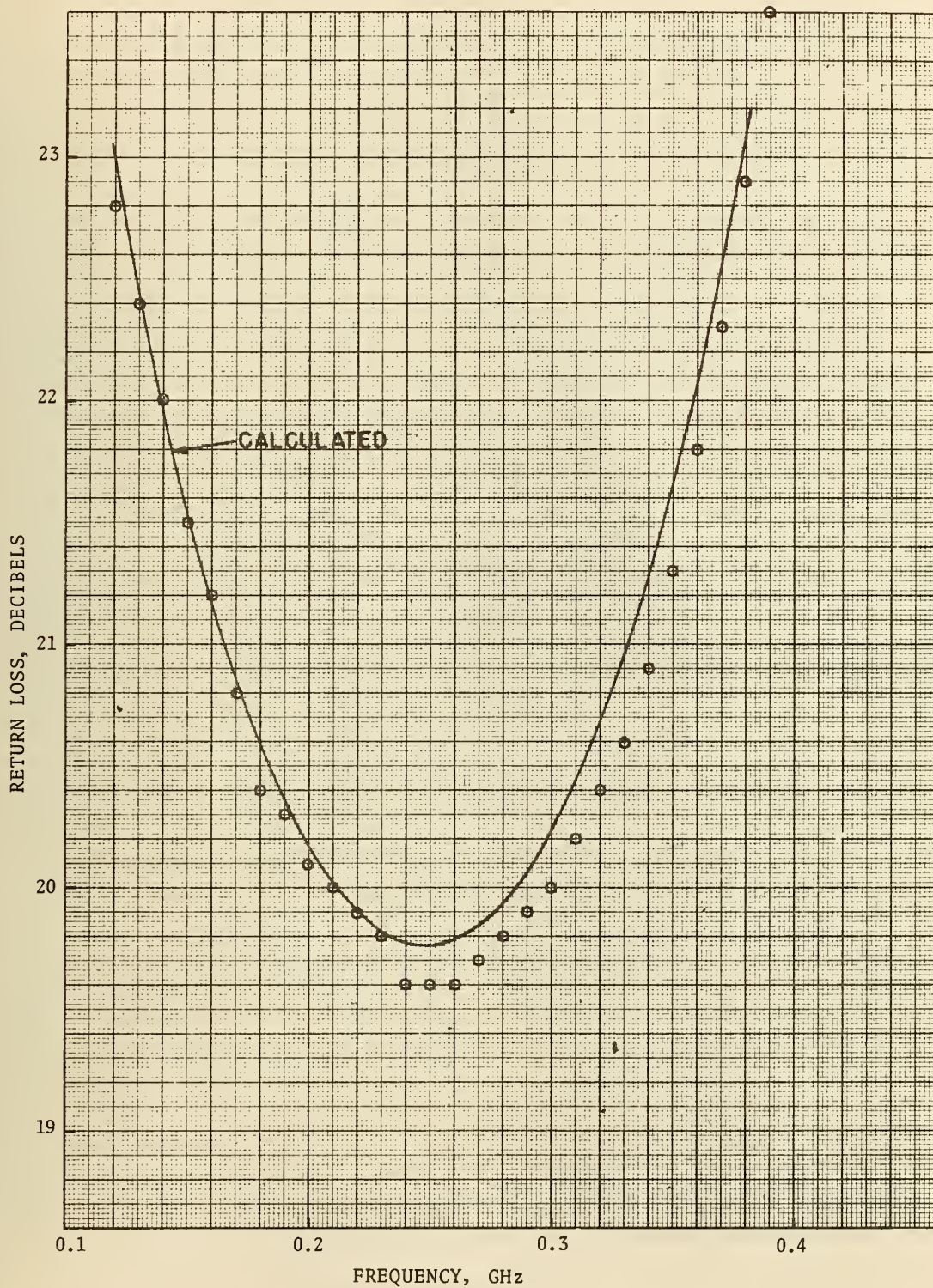


Figure 17. Calculated and measured return loss $= -20 \log_{10} |S_{11}|$ versus frequency for increased ODIC coaxial 2-port.

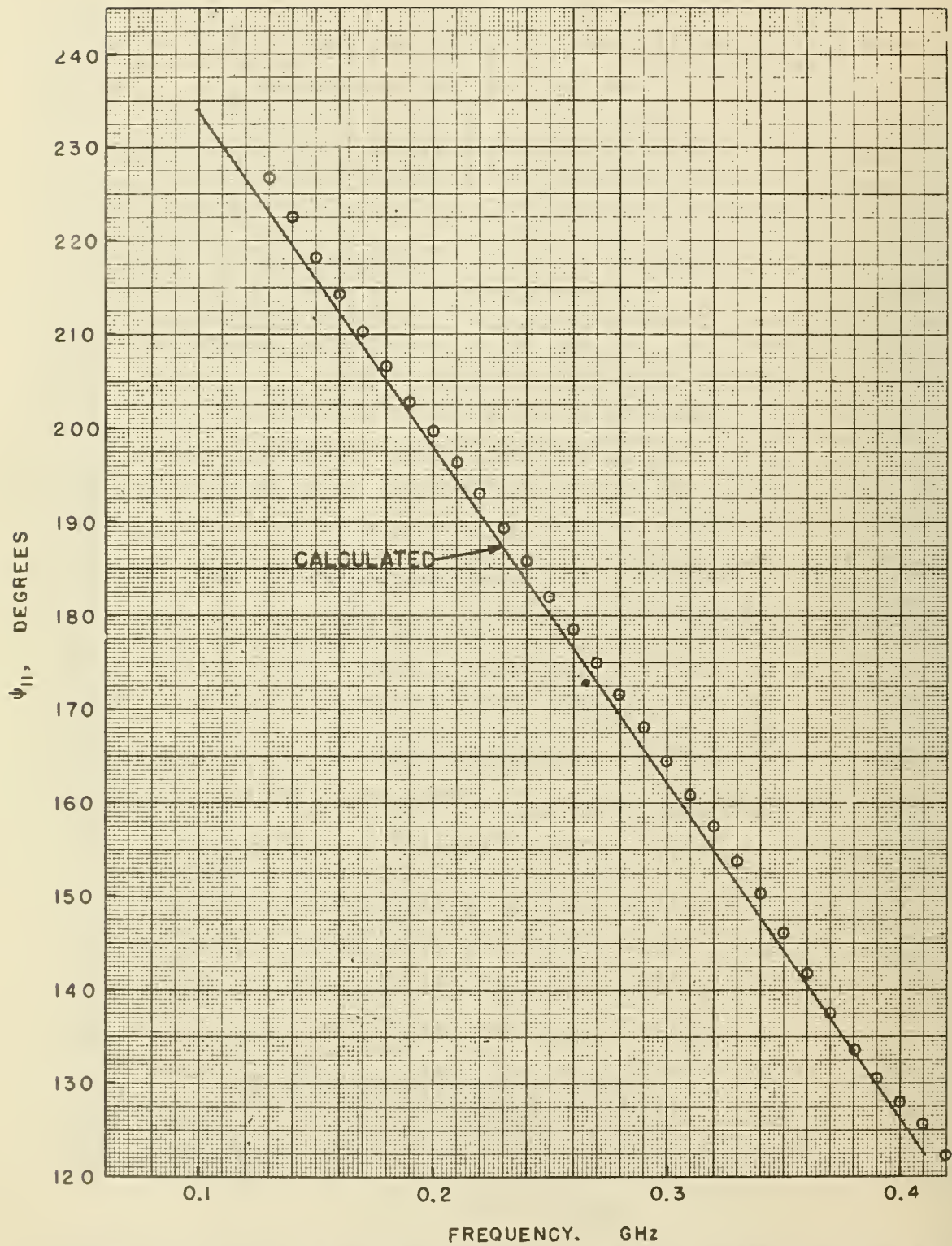


Figure 18. Calculated and measured $\arg(S_{11}) = \psi_{11}$ in degrees versus frequency for increased ODIC coaxial 2-port.

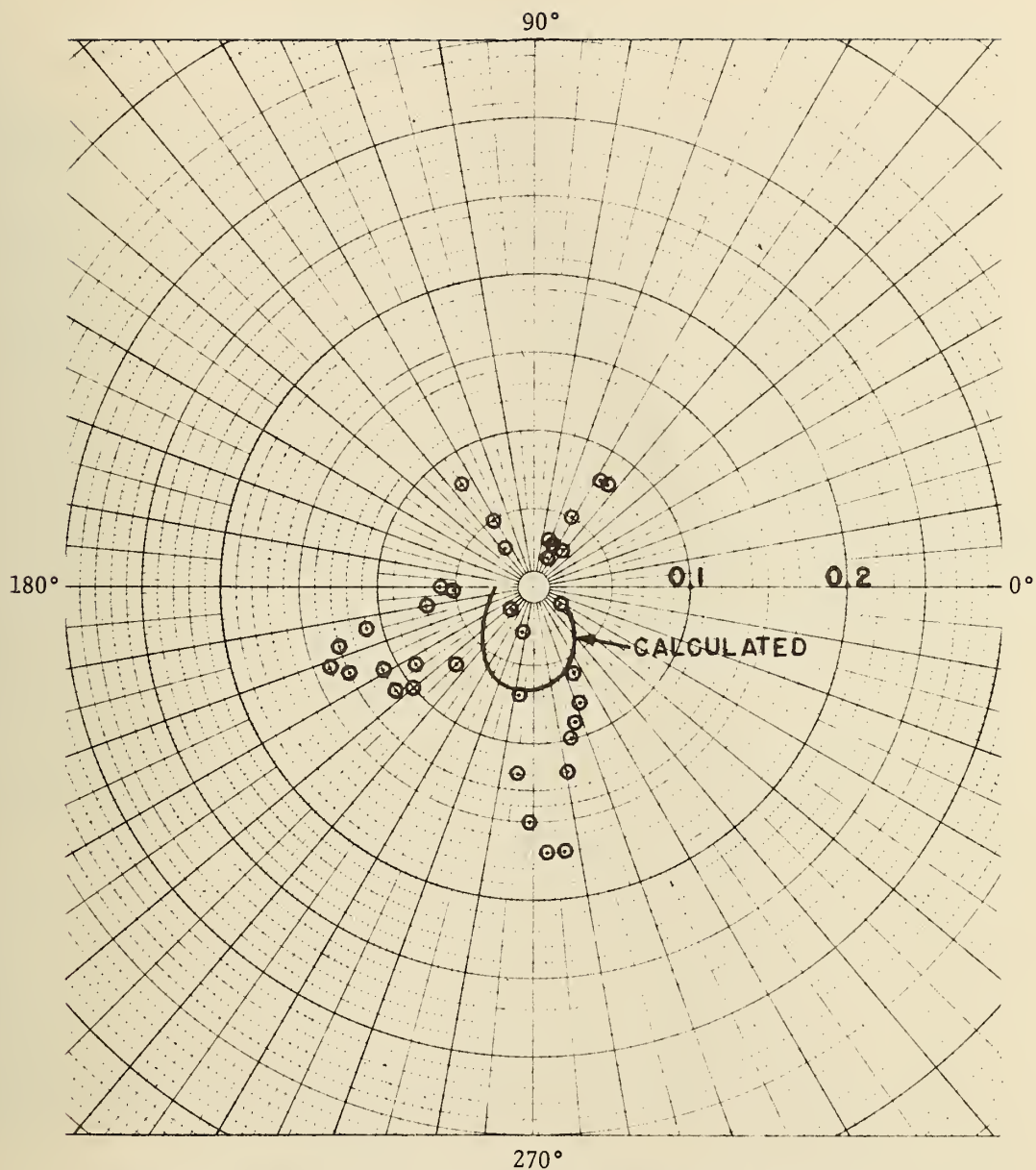


Figure 19. Polar plot of calculated and measured attenuation in decibels $= -20 \log_{10} |S_{21}|$ and $\arg(S_{21}) = \psi_{21}$ of increased ODIC coaxial 2-port for frequencies from 0.1 to 0.5 GHz.

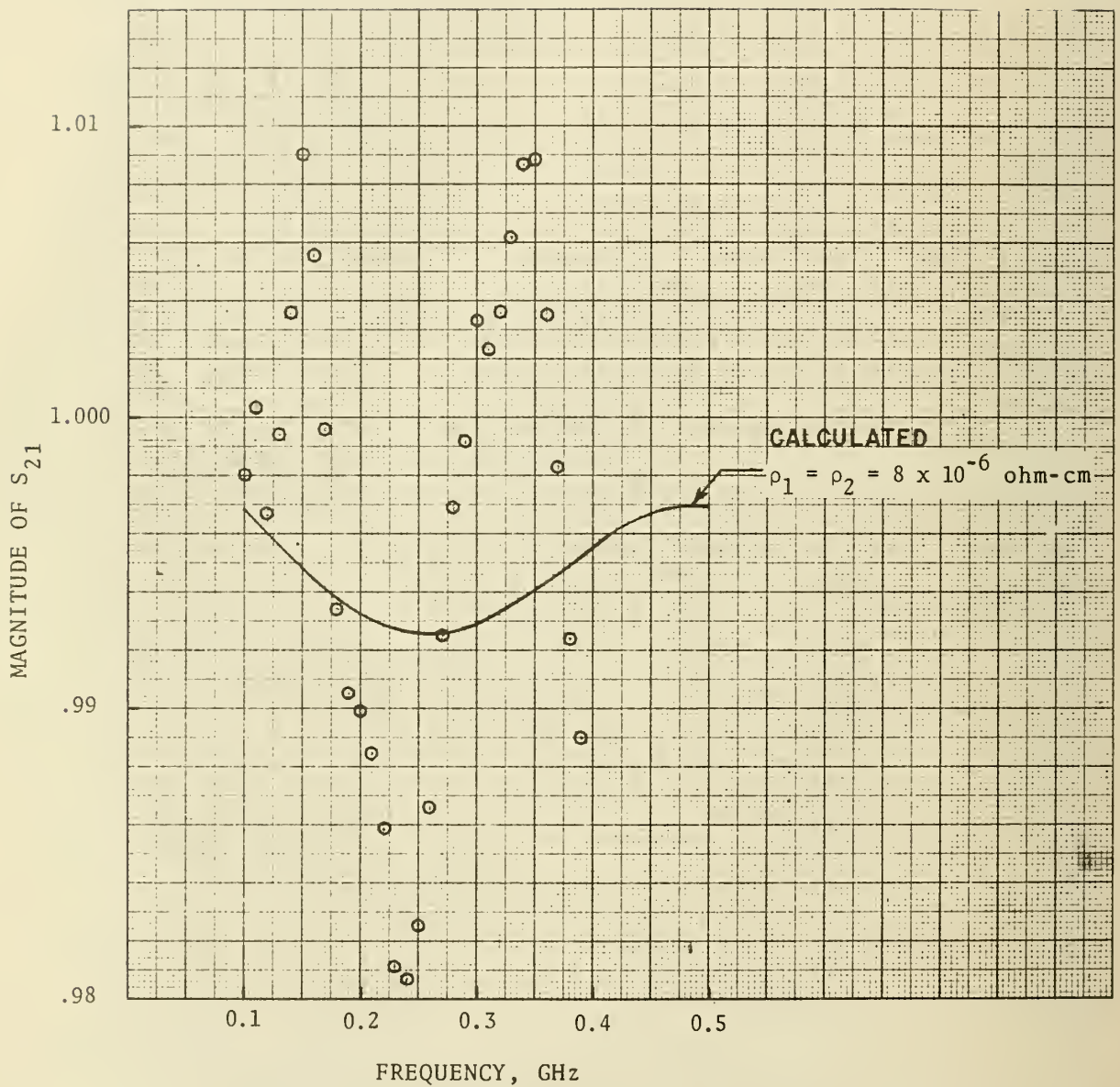


Figure 20. Calculated and measured $|S_{21}|$ versus frequency for increased ODIC coaxial 2-port.

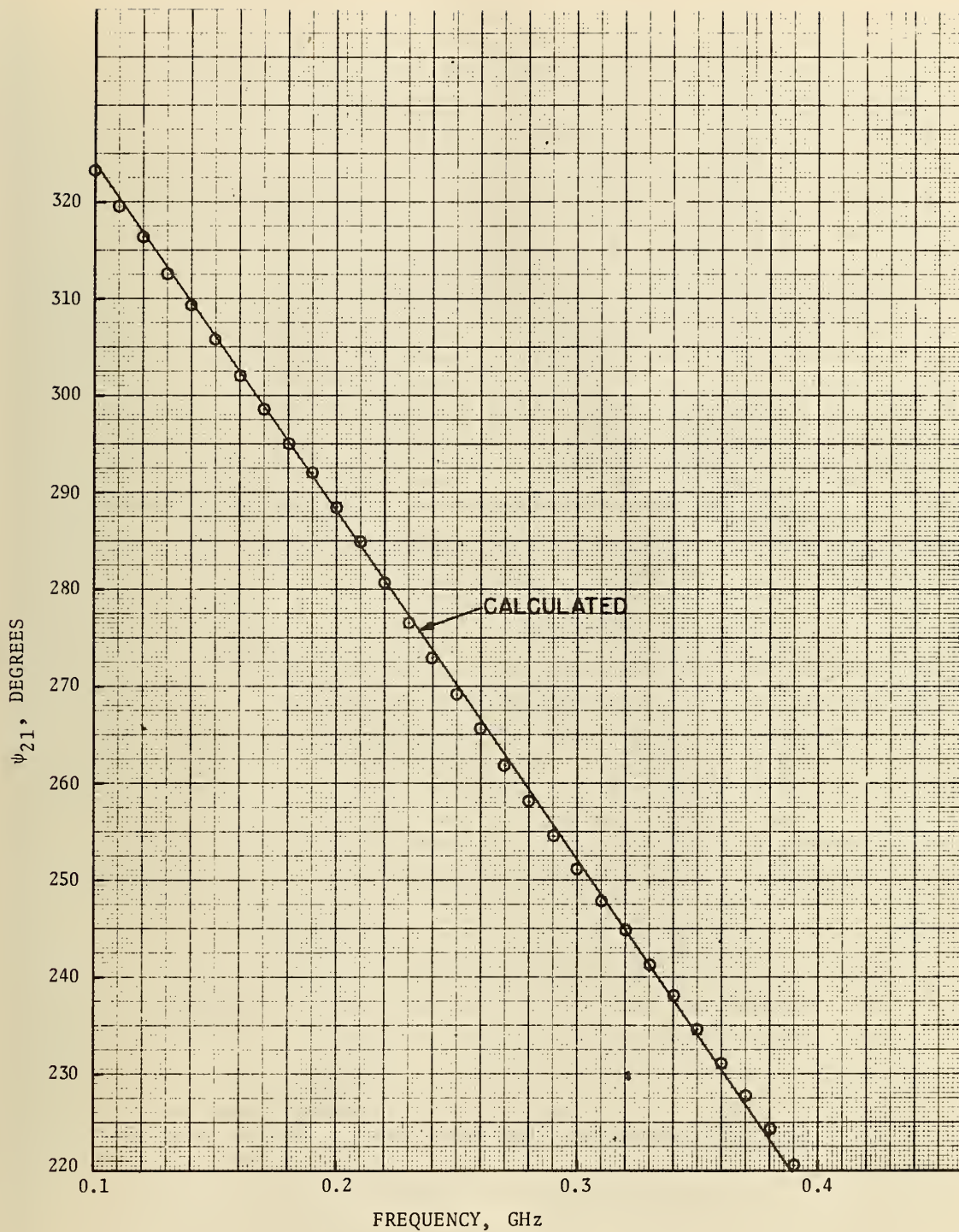


Figure 21. Calculated and measured $\arg(S_{21}) = \psi_{21}$ versus frequency for increased ODIC coaxial 2-port.

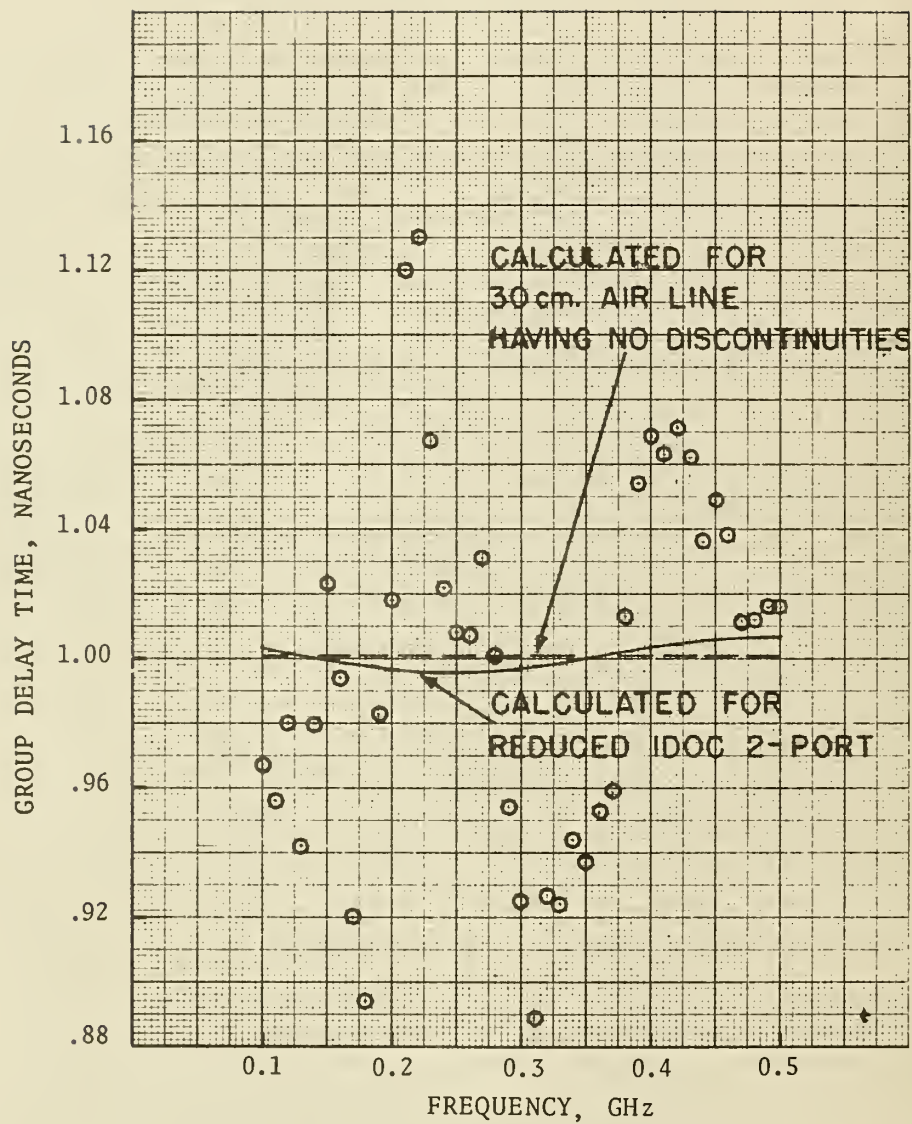
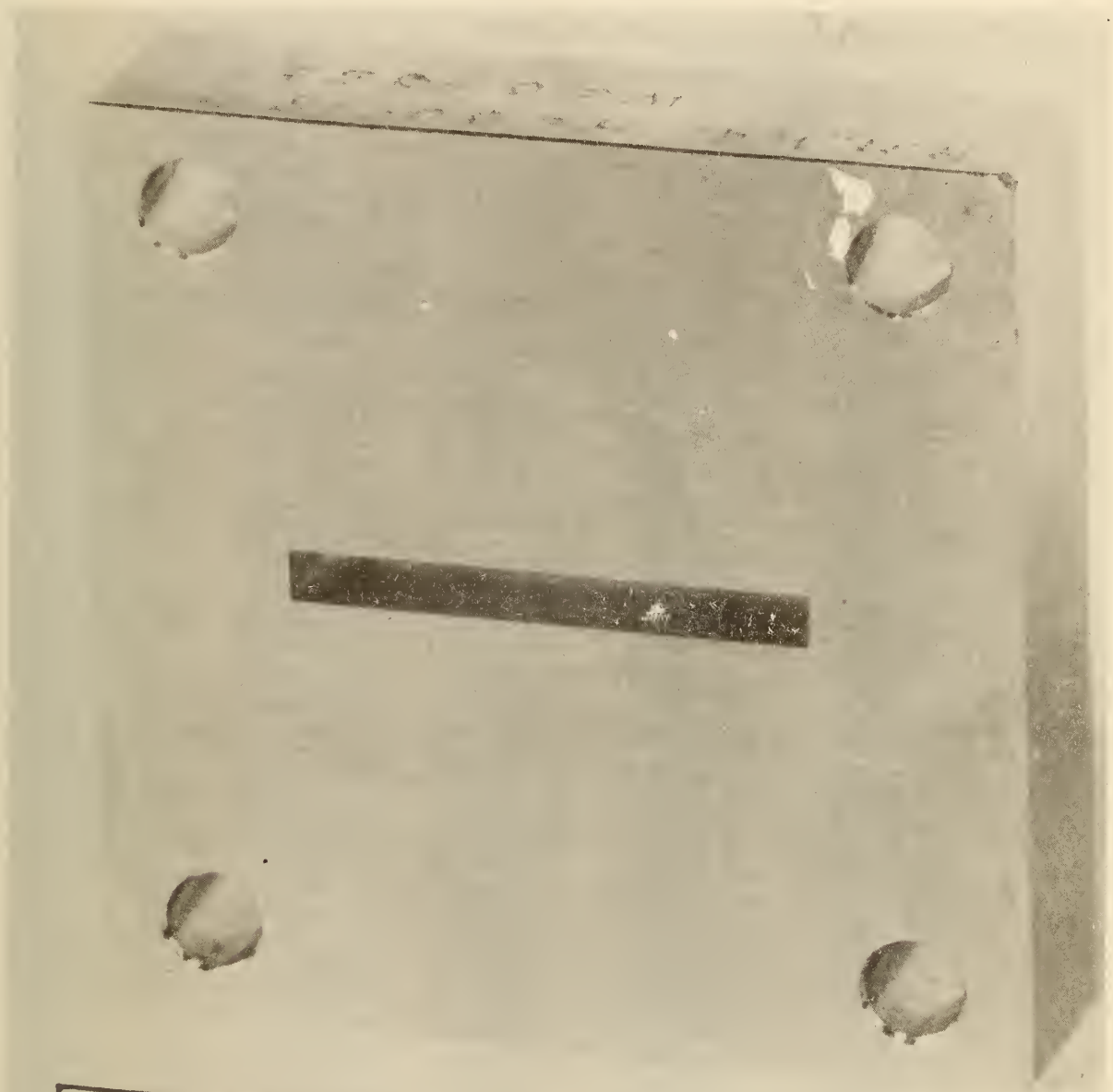


Figure 22. Calculated and measured group delay time versus frequency for increased ODIC coaxial 2-port.



REDUCED HEIGHT WAVEGUIDE
 $L=0.4052''$, $h_R=0.0918''$

Figure 23. Photograph of reduced height rectangular waveguide 2-port designed to be inserted into a WR-90 (IEC-R-100) waveguide system.

WS11 13:54 06/05/74

FOR WR-90 (R-100) WAVEGUIDE SYSTEM:

INTERNAL WIDTH .9 INCHES
INTERNAL HEIGHT .4 INCHES

FOR 2-PORT:

INTERNAL WIDTH .9 INCHES
INTERNAL HEIGHT .0918 INCHES
LENGTH .4052 INCHES
RESISTIVITY 8.5E-6 OHM-CM.
RELATIVE PERMITTIVITY OF AIR 1.00064

FREQUENCY GHZ	RETURN LOSS DECIBELS	MAG(S11)	ARG(S11) DEGREES
8	1.05701	.88542	192.856
8.1	1.02289	.888905	191.71
8.2	.994234	.891843	190.621
8.3	.970268	.894307	189.583
8.4	.950387	.896356	188.586
8.5	.934112	.898037	187.624
8.6	.92106	.899388	186.693
8.7	.910931	.900437	185.788
8.8	.903484	.90121	184.904
8.9	.898529	.901724	184.038
9.	.89592	.901995	183.187
9.1	.895548	.902033	182.347
9.2	.897331	.901848	181.517
9.3	.901219	.901445	180.693
9.4	.907183	.900826	179.873
9.5	.91522	.899993	179.055
9.6	.925345	.898944	178.236
9.7	.937597	.897677	177.416
9.8	.952034	.896186	176.591
9.9	.968736	.894465	175.759
10.	.987805	.892503	174.919
10.1	1.00936	.890291	174.068
10.2	1.03356	.887814	173.205
10.3	1.06058	.885056	172.327
10.4	1.09062	.882001	171.431
10.5	1.12392	.878626	170.517
10.6	1.16075	.874908	169.58
10.7	1.20144	.870819	168.619
10.8	1.24635	.866328	167.631
10.9	1.2959	.8614	166.613
11.	1.35058	.855995	165.561
11.1	1.41093	.850067	164.473
11.2	1.47761	.843566	163.345
11.3	1.55136	.836434	162.174
11.4	1.63304	.828606	160.954
11.5	1.72364	.820008	159.681
11.6	1.82433	.810557	158.352
11.7	1.93646	.80016	156.959
11.8	2.06163	.788712	155.499
11.9	2.20171	.776094	153.964
12.	2.35891	.762175	152.349
12.1	2.53584	.746806	150.646
12.2	2.73562	.729826	148.847
12.3	2.96198	.711051	146.946
12.4	3.21941	.690287	144.934
12.5	3.51333	.667319	142.803
12.6	3.85036	.641922	140.544
12.7	4.23865	.613858	138.149
12.8	4.68828	.582889	135.612
12.9	5.21199	.548783	132.925
13.	5.82604	.511326	130.083

Figure 24. Computer printout of program WS11 for rectangular waveguide 2-port.

WS21 14:00 06/05/74

FOR WR-90 (R-100) WAVEGUIDE SYSTEM:

INTERNAL WIDTH
INTERNAL HEIGHT

.9 INCHES
.4 INCHES

FOR 2-PORT:

INTERNAL WIDTH
INTERNAL HEIGHT
LENGTH
RESISTIVITY
RELATIVE PERMITTIVITY OF AIR

.9 INCHES
.0918 INCHES
.4052 INCHES
8.5E-6 OHM-CM.
1.00064

DELTA F FOR CALCULATION OF GROUP DELAY

.05 GHZ

FREQUENCY GHZ	ATTENUATION DECIBELS	MAG(S21)	ARG(S21) DEGREES	GROUP DELAY NANOSECONDS
8	6.67891	.463505	-77.1143	3.28741E-2
8.1	6.80454	.456849	-78.2646	3.11083E-2
8.2	6.91374	.451142	-79.3565	2.96136E-2
8.3	7.00779	.446283	-80.3988	2.83439E-2
8.4	7.08778	.442192	-81.399	2.72637E-2
8.5	7.15464	.438801	-82.3633	.026345
8.6	7.20917	.436055	-83.2971	2.55655E-2
8.7	7.25206	.433907	-84.2051	2.49077E-2
8.8	7.28389	.43232	-85.0914	2.43571E-2
8.9	7.30517	.431262	-85.9596	2.39024E-2
9.	7.31635	.430708	-86.8131	2.35343E-2
9.1	7.3178	.430635	-87.6548	2.32451E-2
9.2	7.30987	.431029	-88.4874	2.30289E-2
9.3	7.29283	.431875	-89.3135	2.28808E-2
9.4	7.26693	.433165	269.865	2.27972E-2
9.5	7.23239	.434891	269.045	2.27748E-2
9.6	7.18938	.43705	268.224	2.28119E-2
9.7	7.13807	.439639	267.402	2.29067E-2
9.8	7.07857	.442661	266.574	2.30588E-2
9.9	7.011	.446118	265.741	2.32676E-2
10.	6.93545	.450015	264.899	2.35337E-2
10.1	6.85199	.454361	264.046	2.38577E-2
10.2	6.76066	.459163	263.18	.024241
10.3	6.66151	.464434	262.3	2.46857E-2
10.4	6.55457	.470188	261.402	2.51937E-2
10.5	6.43986	.476439	260.485	2.57683E-2
10.6	6.31738	.483205	259.546	2.64126E-2
10.7	6.18714	.490505	258.583	2.71308E-2
10.8	6.04913	.49836	257.592	2.79275E-2
10.9	5.90336	.506795	256.572	2.88077E-2
11.	5.74982	.515833	255.517	2.97774E-2
11.1	5.58852	.525502	254.427	3.08432E-2
11.2	5.41945	.53583	253.296	3.20122E-2
11.3	5.24266	.546849	252.121	3.32928E-2
11.4	5.05817	.558588	250.898	3.46936E-2
11.5	4.86606	.57108	249.622	3.62244E-2
11.6	4.66642	.584358	248.288	3.78958E-2
11.7	4.45939	.598454	246.892	3.97188E-2
11.8	4.24517	.613397	245.427	4.17054E-2
11.9	4.02402	.629215	243.887	4.38683E-2
12.	3.79627	.645931	242.267	.04622
12.1	3.56238	.663561	240.558	4.87729E-2
12.2	3.3229	.682111	238.753	5.15394E-2
12.3	3.07855	.701573	236.845	5.45295E-2
12.4	2.8302	.721922	234.825	5.77519E-2
12.5	2.57895	.743109	232.685	6.12109E-2
12.6	2.32613	.765056	230.416	6.49053E-2
12.7	2.07333	.78765	228.009	6.88268E-2
12.8	1.82246	.810731	225.458	.072957
12.9	1.57575	.834089	222.755	7.72647E-2
13.	1.33576	.857456	219.894	8.17034E-2

NOW AT 999
SRU'S:1.1
READY

Figure 25. Computer printout of program WS21 for rectangular waveguide 2-port.

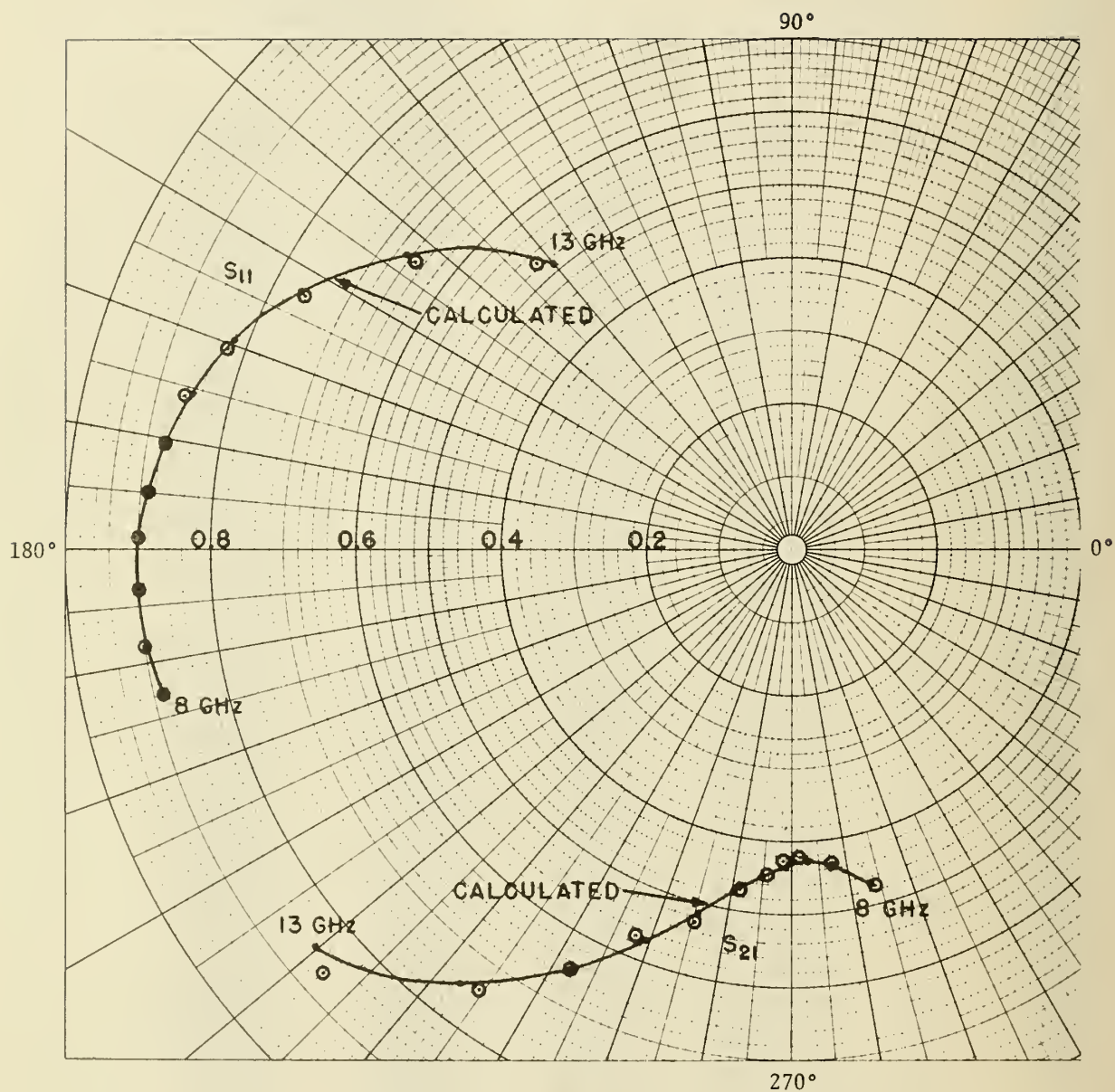


Figure 26. Polar plot of calculated and measured S_{11} and S_{21} of rectangular waveguide 2-port for frequencies from 8 to 13 GHz.

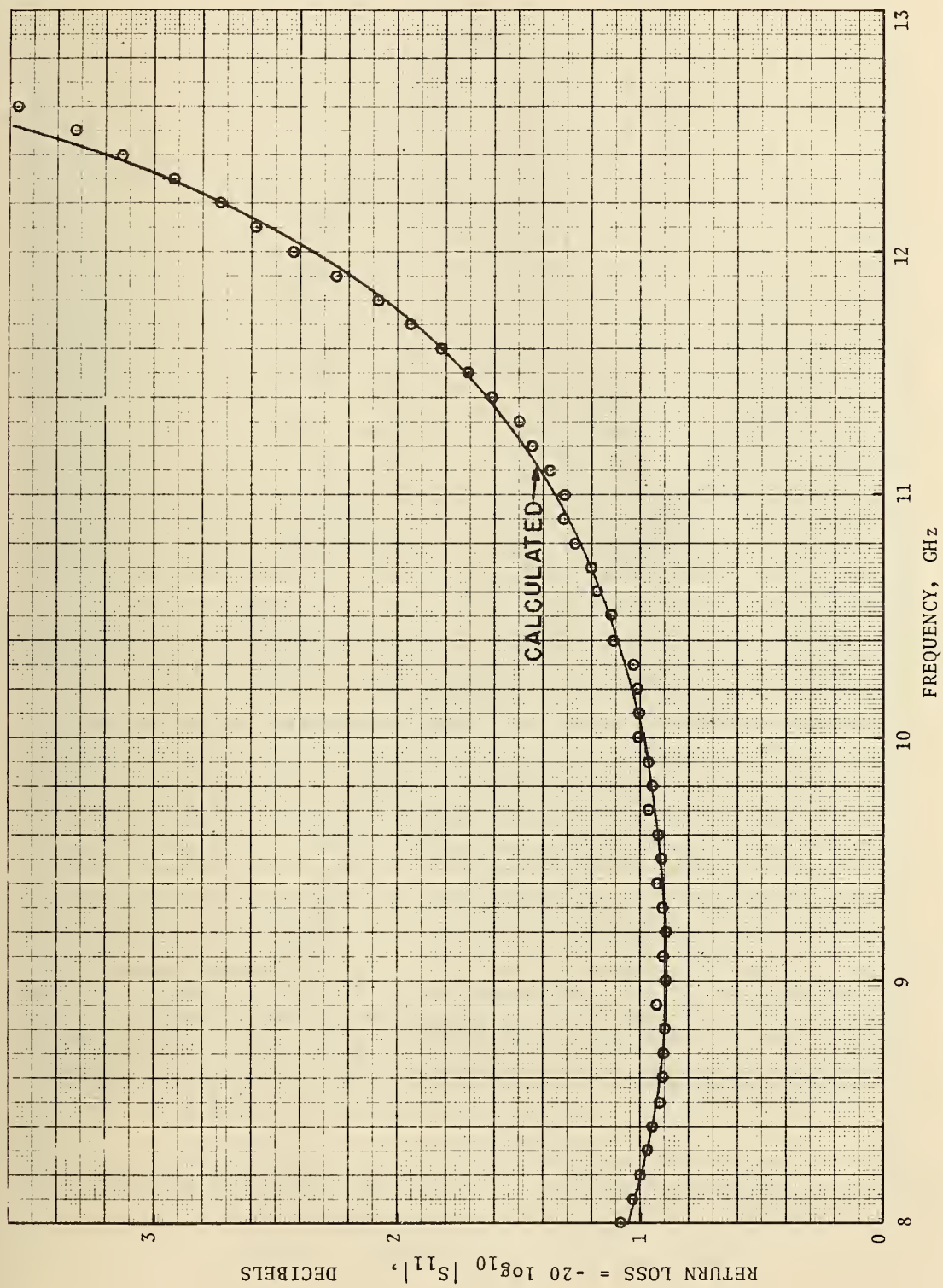


Figure 27. Calculated and measured return loss = $-20 \log_{10} |S_{11}|$ versus frequency for rectangular waveguide 2-port.

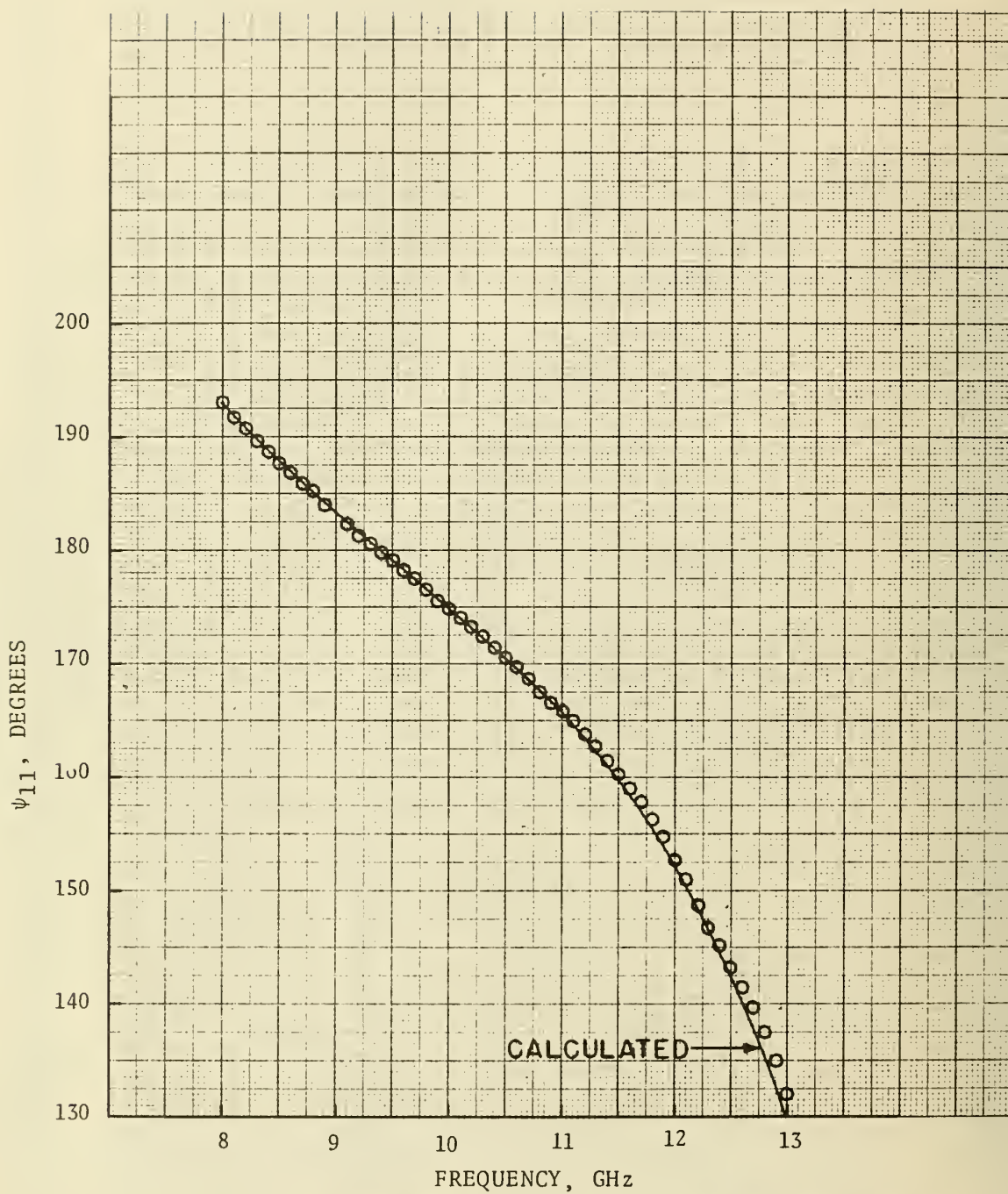


Figure 28. Calculated and measured $\arg(S_{11}) = \psi_{11}$ in degrees versus frequency for rectangular waveguide 2-port.

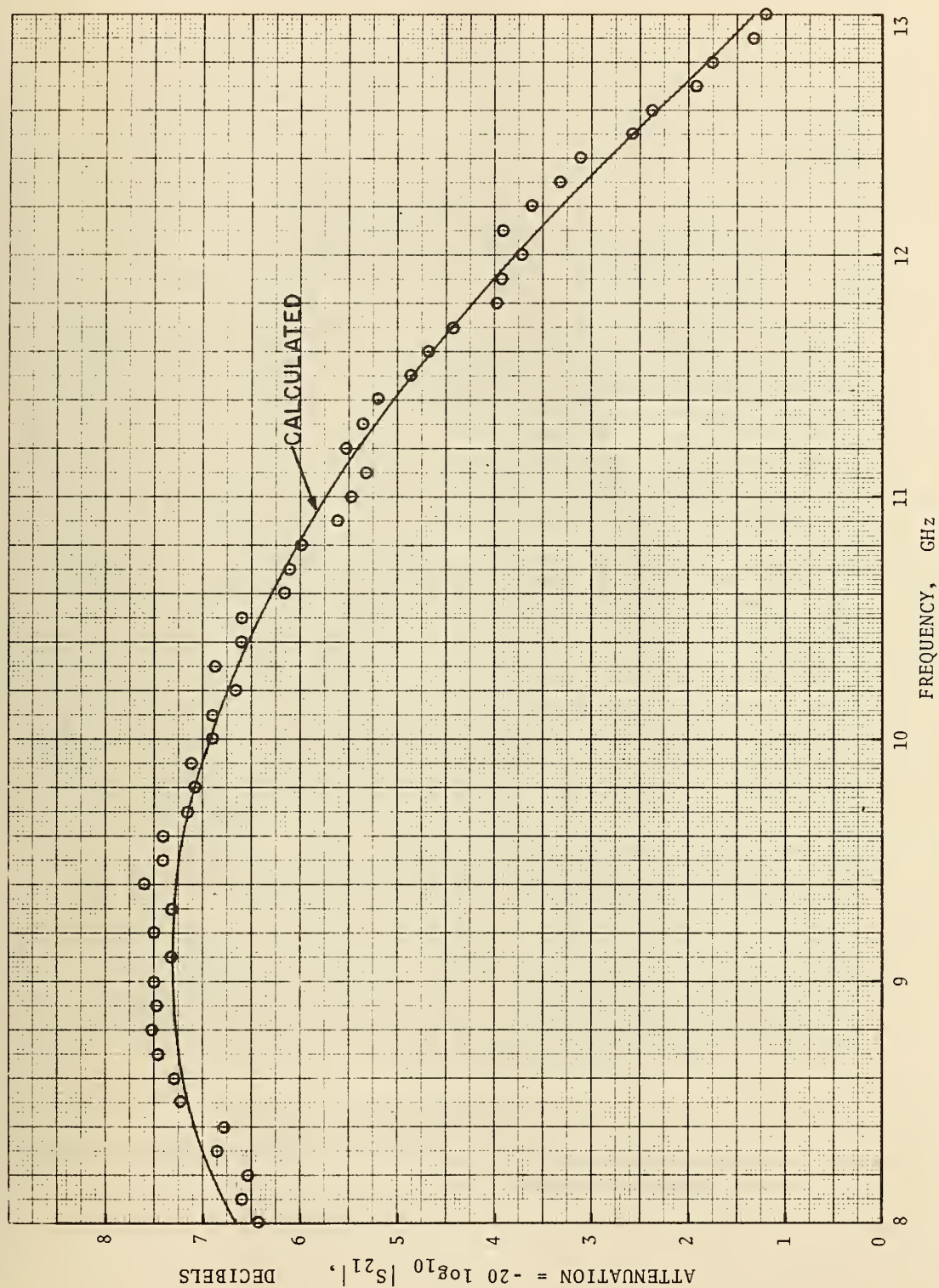


Figure 29. Calculated and measured attenuation = $-20 \log_{10} |S_{21}|$ versus frequency for rectangular waveguide 2-port.

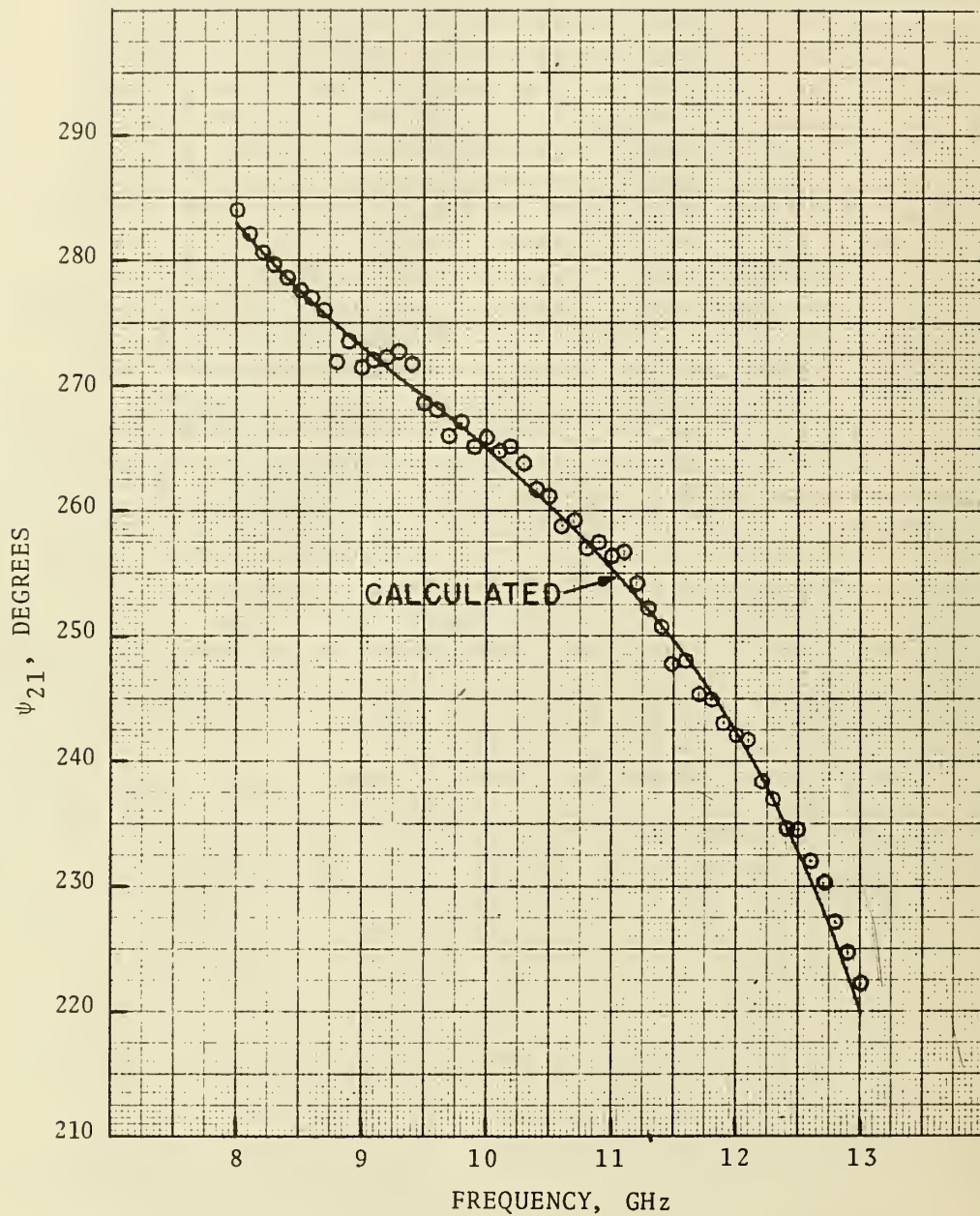


Figure 30. Calculated and measured $\arg(S_{21}) = \psi_{21}$ in degrees versus frequency for rectangular waveguide 2-port.

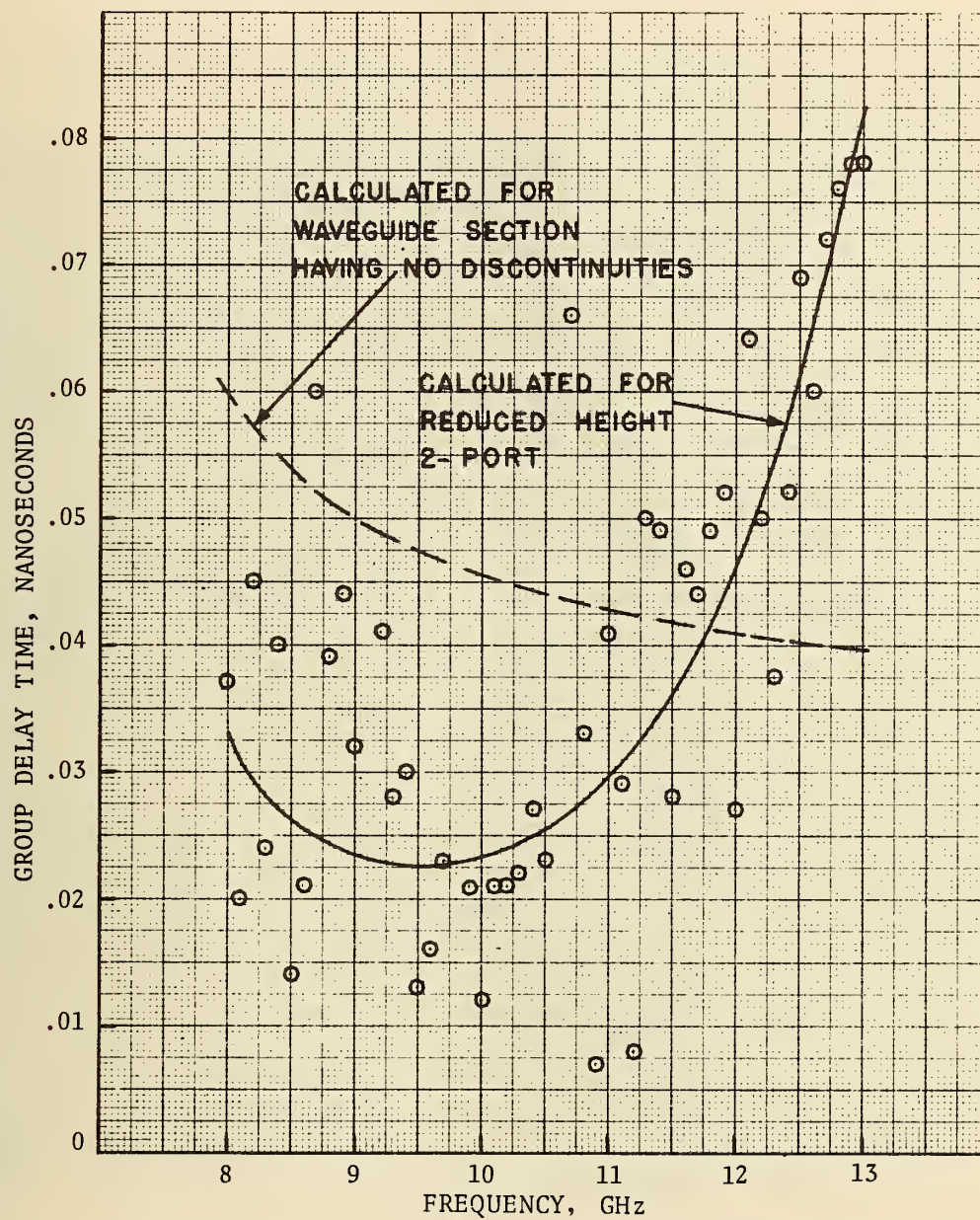


Figure 31. Calculated and measured group delay time versus frequency for rectangular waveguide 2-port.

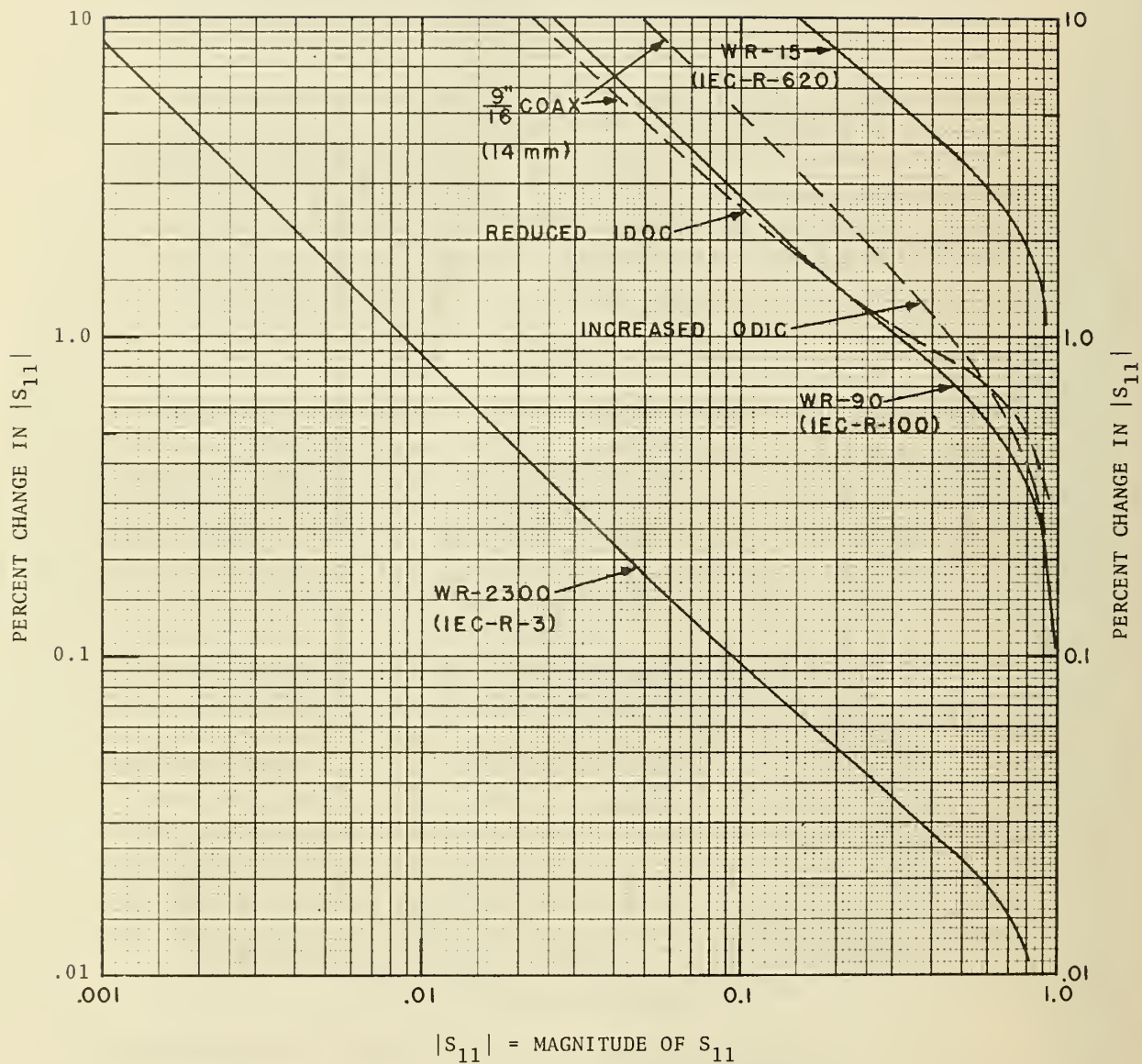


Figure 32. Percent change in $|S_{11}|$ versus $|S_{11}|$ of $\lambda_G/4$ 2-port standards corresponding to a change of 0.001 inch in the increased ODIC or reduced IDOC of 9/16 inch (14 mm) coaxial 2-ports or reduced height rectangular waveguide 2-ports.

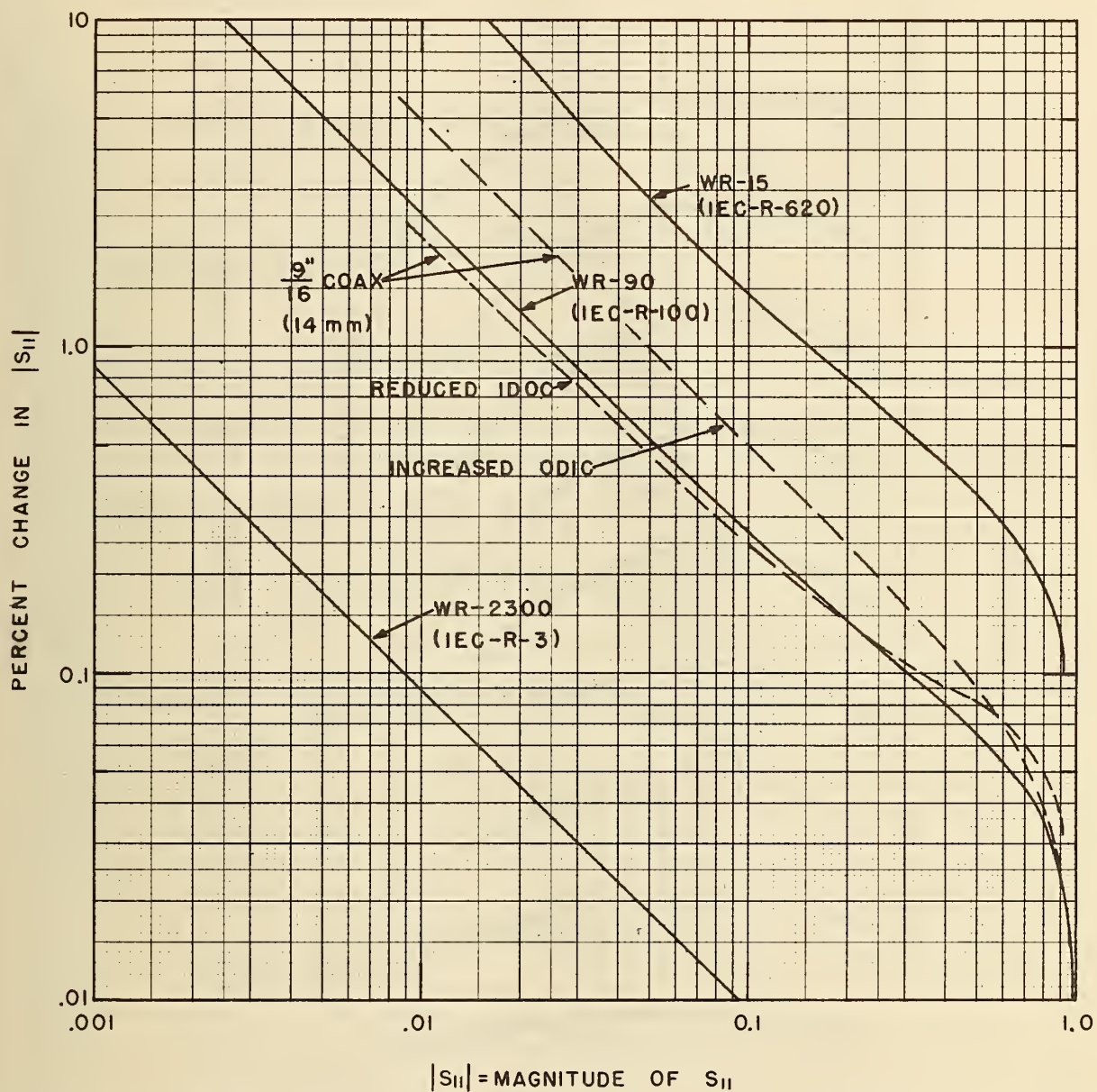


Figure 33. Percent change in $|S_{11}|$ versus $|S_{11}|$ of $\lambda_G/4$ 2-port standards corresponding to a change of 0.0001 inch in the increased ODIC or reduced IDOC of 9/16 inch (14 mm) coaxial 2-ports, or reduced height rectangular waveguide 2-ports.

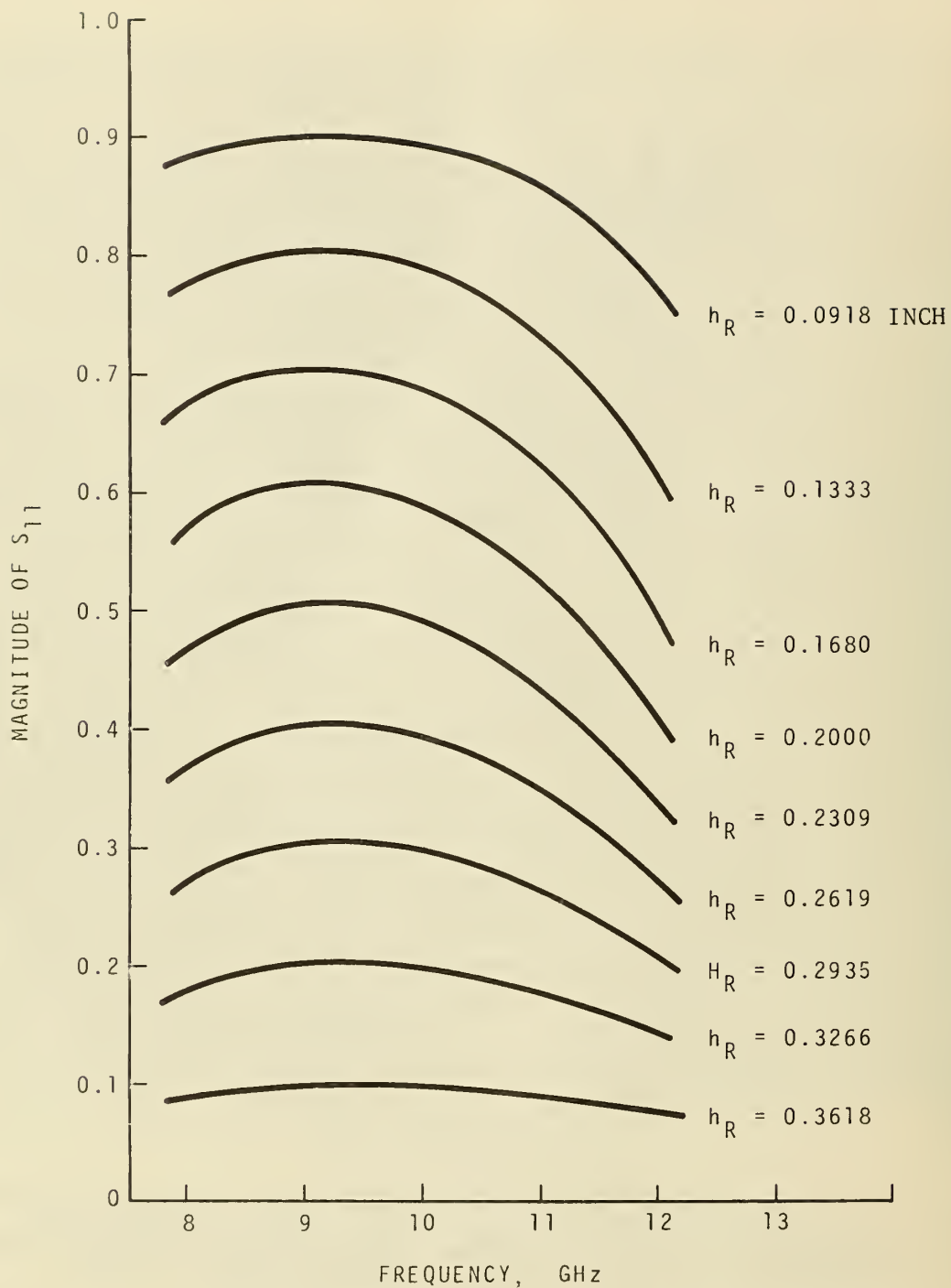


Figure 34. Calculated $|S_{11}|$ versus frequency for various reduced height WR-90 (IEC-R-100) rectangular waveguide 2-port standards all having a length of 0.4052 inch.

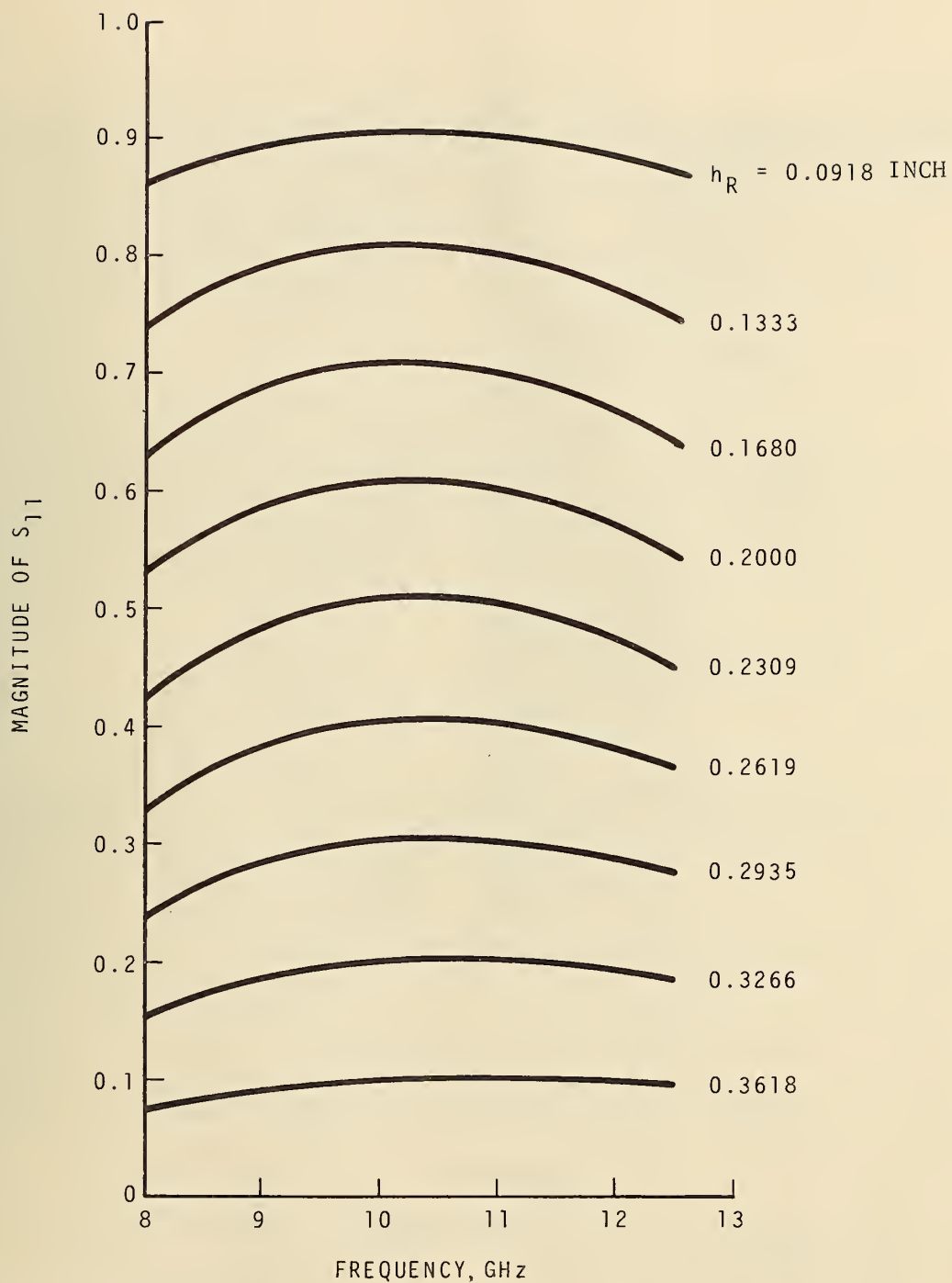


Figure 35. Calculated $|S_{11}|$ versus frequency for various reduced height WR-90 (IEC-R-100) rectangular waveguide 2-port standards all having a length of 0.3150 inch (80 mm).

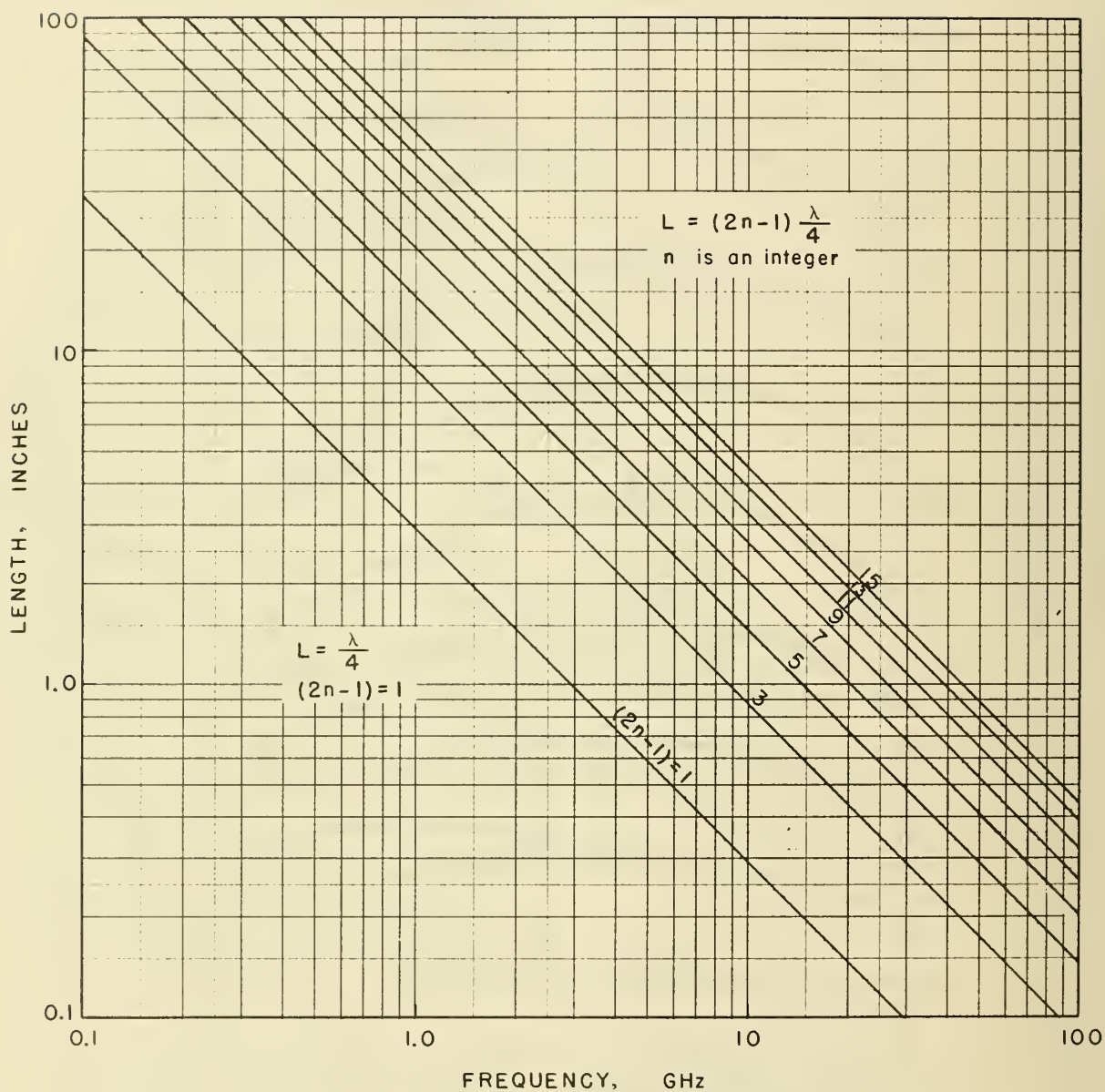


Figure 36. Plot of $L = (2n-1) \lambda_G/4$ versus frequency for TEM mode propagation in coaxial line.

Appendix CS11

CS11 09:01 06/04/74

```

1REM
2REM INPUT DATA REQUIRED:
3REM
4REM
5REM FOR COAXIAL SYSTEM INTO WHICH 2-PORT IS INSERTED:
6REM COAXIAL SYSTEM DESIGNATOR.....LINE 250
7REM ODIC (INCHES).....LINE 205 A1
8REM IDOC (INCHES).....LINE 215 B1
9REM IDOC (INCHES).....LINE 215 B1
10REM FOR REDUCED IDOC 2-PORT STANDARD:
11REM ODIC (INCHES).....LINE 210 A2
12REM IDOC (INCHES).....LINE 220 B2
13REM LENGTH (INCHES).....LINE 225 L
14REM IC RESISTIVITY (OHM-CM.).....LINE 230 P1
15REM OC RESISTIVITY (OHM-CM.).....LINE 235 P2
16REM DISCONTINUITY CAPACITANCE DIVIDED BY CIRCUMFER-
17REM ENCE OF IC (FARADS/CM.).....LINE 240 C1
18REM (NOTE THAT C1 IS ASSUMED INDEPENDENT OF
19REM FREQUENCY AND IS NOT CALCULATED BY THIS PRO-
20REM GRAM BUT MUST BE OBTAINED BY OTHER MEANS)
21REM RELATIVE PERMITTIVITY OF AIR.....LINE 200 E
22REM FREQUENCIES (GHZ).....LINE 329 F
23REM
24REM CALCULATED PARAMETERS:
25REM TEM MODE Z0 OF COAXIAL SYSTEM (OHMS).....LINE 305 Z1
26REM TEM MODE Z0 OF 2-PORT (OHMS).....LINE 310 Z2
27REM DISCONTINUITY CAPACITANCE (FARADS).....LINE 360 C2
28REM DISCONTINUITY SUSCEPTANCE/Y02.....LINE 370 E7
29REM (NOTE THAT Y02=1/Z02)
30REM GUIDE WAVELENGTH (INCHES).....LINE 330 W
31REM IC SKIN DEPTH (CM.).....LINE 335 K1
32REM OC SKIN DEPTH (CM.).....LINE 340 K2
33REM ATTENUATION CONSTANT OF 2-PORT(N/CM).....LINE 345 A
34REM (ATTEN. CONST.)*(LENGTH)---(DB).....LINE 355 A7
35REM RETURN LOSS (DB) CORRESPONDING TO S11.....LINE 481 T5
36REM MAGNITUDE OF S11.....LINE 480 S
37REM ARGUMENT OF S11 (DEGREES).....LINE 500 T3
38REM (NOTE THAT IF G1<0 THEN T3+180)
39REM
40REM 100P=3.14159265
41REM 105 C=2.997925*10+10
42REM 110N=8.68589
43REM 115N1=2.54
44REM 125 N3=.5/P
45REM 200E=1.00064
46REM 205A1=.24425
47REM 210A2=.24425
48REM 215B1=.5625
49REM 220B2=.5185
50REM 225 L=30/N1
51REM 230 P1=2/10+6
52REM 235 P2=8/10+6
53REM 240 C1=1.94969/10+15
54REM 245V=C/(N1*50R(E))
55REM 246Z1=59.9392*LOG(B1/A1)
56REM 247Z2=59.9392*LOG(B2/A2)
57REM 248C9=2.302585093
58REM 250PRINT"FOR 9/16 INCH (14 MM) COAXIAL SYSTEM:"
59REM 251PRINT" ODIC "A1;"INCHES"
60REM 252PRINT" IDOC "B1;"INCHES"
61REM 253PRINT" TEM-MODE CHARACTERISTIC IMPEDANCE "Z1;"OHMS"
62REM
63REM 254PRINT
64REM 255PRINT"FOR 2-PORT:"
65REM 256PRINT" ODIC "A2;"INCHES"
66REM 257PRINT" IDOC "B2;"INCHES"
67REM 258PRINT" LENGTH "L;"INCHES"
68REM 259PRINT" TEM-MODE CHARACTERISTIC IMPEDANCE "Z2;"OHMS"
69REM 260PRINT" DISCONTINUITY CAPACITANCE "C1*P*A1*N1;"FARADS"
70REM 261PRINT" RELATIVE PERMITTIVITY OF AIR "E
71REM 262PRINT" IC RESISTIVITY "P1;"OHM-CM."
72REM 263PRINT" OC RESISTIVITY "P2;"OHM-CM."
73REM 264PRINT
74REM 315R1=Z1/Z2
75REM 320R2=R1+2
76REM 323PRINT
77REM 324PRINT"FREQUENCY","RETURN LOSS"," "ARG(S11)"
78REM 325PRINT" GHZ "DECI BELS","MAG(S11)","DEGREES"
79REM 326PRINT
80REM 329FOR F=.1 TO.55STEP.01
81REM 330 W=V/(F*10+9)
82REM 335K1=N3*50R(P1/F)
83REM 340K2=N3*50R(P2/F)
84REM 345 A=2*P*F*((K1/A2)+(K2/B2))/(N1*Z2)
85REM 350 A6=2*A*L*N1
86REM 355A7=A6*N/2
87REM 360C2=P*A1*N1*C1
88REM 365 B3=2*P*F*C2*10+9
89REM 370 E7=Z2*B3
90REM 375 B=4*P*L/W
91REM 380S5=51N(B)
92REM 385C5=C05(B)
93REM 390A9=1-A6
94REM 395C6=E7*E7*R2
95REM 400R3=(1-R2+C6)*(1-A9*C5)
96REM 405R4=-2*E7*R2*A9*55
97REM 410R5=R3+R4
98REM 415I1=-2*E7*R2*(1+A9*C5)
99REM 420I2=(1-R2+C6)*A9*55
100REM 425I3=I1+I2
101REM 430M1=50R(R5+2+I3+2)
102REM 435R6=(1+R1)+2-C6
103REM 440R7=((1-R1)+2-(E7*R1)+2)*C5
104REM 445R8=(2*E7*R1)*(1-R1)*55
105REM 450R9=R6-A9*(R7+R8)
106REM 455I4=(2*E7*R1)*(1+R1)
107REM 460I5=R7*TAN(B)
108REM 465I6=-2*E7*R1*(1-R1)*C5
109REM 470I7=I4+(1-A6)*(I5+I6)
110REM 475M2=50R(R9+2+I7+2)
111REM 480S =M1/M2
112REM 481T5=(20*LOG(1/S))/C9
113REM 485G1=(R5*R9+I3*I7)/(R9*R9+I7*I7)
114REM 490G2=(I3*R9-R5*I7)/(R9*R9+I7*I7)
115REM 495G3=ATN(G2/G1)
116REM 500T3=G3*180/P
117REM 505IF G1<0 THEN 520
118REM 510PRINT F,T5,S,T3
119REM 515IF G1>0 THEN 525
120REM 520PRINT F,T5,S,T3+180
121REM 525NEXT F

```

```

2REM INPUT DATA REQUIRED:
4REM
6REM FOR COAXIAL SYSTEM INTO WHICH 2-PORT IS INSERTED:
7REM COAXIAL SYSTEM DESIGNATOR.....LINE 296
8REM ODIC (INCHES).....LINE 135 A1
10REM IDOC (INCHES).....LINE 145 B1
12REM FOR REDUCED IDOC 2-PORT STANDARD:
14REM ODIC (INCHES).....LINE 140 A2
16REM IDOC (INCHES).....LINE 150 B2
18REM LENGTH (INCHES).....LINE 155 L
20REM IC RESISTIVITY (OHM-CM.).....LINE 160 P1
22REM OC RESISTIVITY (OHM-CM.).....LINE 165 P2
24REM DISCONTINUITY CAPACITANCE DIVIDED BY CIRCUMFER-
26REM ENCE OF IC (FARADS/CM.).....LINE 170 C5
28REM (NOTE THAT C5 IS ASSUMED INDEPENDENT OF FRE-
30REM QUENCY AND IS NOT CALCULATED BY THIS PRO-
32REM GRAM BUT MUST BE OBTAINED BY OTHER MEANS)
34REM RELATIVE PERMITTIVITY OF AIR.....LINE 130 E
36REM FREQUENCIES (GHZ).....LINE 400 F
37REM
38REM DELTA F FOR GROUP DELAY CALCULATION...LINE 205 M3
40REM
41REM CALCULATED PARAMETERS:
42REM
44REM TEM MODE Z0 OF COAXIAL SYSTEM (OHMS)..LINE 180 Z1
46REM TEM MODE Z0 OF 2-PORT (OHMS).....LINE 185 Z2
48REM DISCONTINUITY CAPACITANCE (FARADS)....LINE 190 C2
50REM DISCONTINUITY SUSCEPTANCE/Y02.....LINE 480 E7
52REM (NOTE THAT Y02=1/Z02)
54REM GUIDE WAVELENGTH (INCHES).....LINE 420 W
56REM IC SKIN DEPTH (CM.).....LINE 435 K1
58REM OC SKIN DEPTH (CM.).....LINE 440 K2
60REM ATTENUATION OF 2-PORT (DECIBELS)....LINE 811 T5
62REM ATTENUATION CONSTANT OF 2-PORT (N/CM) .LINE 445 A
63REM ATTENUATION CONSTANT*LENGTH (DB)....LINE 460 A7
64REM MAGNITUDE OF S21.....LINE 810 S
66REM ARGUMENT OF S21 (DEGREES).....LINE 860 T3
68REM (NOTE THAT IF G1<0 THEN T3+180)
70REM GROUP DELAY (NANOSECONDS).....LINE 830 K9
72REM (NOTE THAT IF K6*K5>0 THEN LINE LINE 840)
74REM
100P=3.14159265
105C=2.997925*10^10
110N=8.68589
115N1=2.54
125N3=.5/P
130E=1.00064
135A1=.24425
140A2=.24425
145B1=.5625
150B2=.5185
155L=30/N1
160 P1=2/10^6
165 P2=8/10^6
170 C5=1.94969/10^15
175V=C/(N1*SQR(E))
180Z1=59.9392*LOG(B1/A1)
185Z2=59.9392*LOG(B2/A2)
190C2=P*A1*N1*C5
195R1=Z1/Z2
200R2=R1^2
205M3=.005
210C9=2.302585093
296PRINT"FOR 9/16 INCH (14 MM) COAXIAL SYSTEM:"
300 PRINT" ODIC " "A1" "INCHES"
305PRINT" IDOC " "B1" "INCHES"
310 PRINT" TEM-MODE CHARACTERISTIC IMPEDANCE" "Z1" "OHMS"
315PRINT
318PRINT"FOR 2-PORT:"
319 PRINT" ODIC " "A2" "INCHES"
320PRINT" IDOC " "B2" "INCHES"
325PRINT" LENGTH " "L" "INCHES"
330 PRINT" TEM-MODE CHARACTERISTIC IMPEDANCE" "Z2" "OHMS"
335PRINT" DISCONTINUITY CAPACITANCE " "C5*P*A1*N1" "FARADS"
340PRINT" RELATIVE PERMITTIVITY OF AIR " "E"
345PRINT" IC RESISTIVITY " "P1" "OHM-CM."
350PRINT" OC RESISTIVITY " "P2" "OHM-CM."
355PRINT
360 PRINT"DELTA F FOR CALCULATION OF GROUP DELAY" "M3" "GHZ"
365PRINT
366PRINT
370PRINT"FREQUENCY" "ARG(S21)" "GROUP DELAY"
375PRINT" GHZ " "DECIBELS" "MAG(S21)" "DEGREES" "NANOSECONDS"
380PRINT
400FOR F=.1 TO .5 STEP .01
410F1=F*M3
415F2=F*M3
420W=V/(F*10^9)
425W1=W*F/F1
430W2=W*F/F2
435K1=N3*SQR(P1/F)
440K2=N3*SQR(P2/F)
445 A=2*P*F*((K1/A2)+(K2/B2))/(N1*Z2)
450A6=2*A*L*N1
460A7=A6*N/2
465A8=A6*SQR(F1/F)
470A9=A6*SQR(F2/F)
475B5=2*P*F*C2*10^9
480E7=Z2*B5
485E8=E7*(F1/F)
490E9=E7*(F2/F)
495B=4*P*L/W
500B3=B*W/W1
505B4=B*W/W2
600Q1=4*R1*(1-A6/2)*COS(B/2)
605Q6=4*R1*(1-A8/2)*COS(B3/2)
610Q7=4*R1*(1-A9/2)*COS(B4/2)
615H1=4*R1*(1-A6/2)*SIN(B/2)
620M1=SQR(Q1^2+H1^2)
625D1=ATN(H1/Q1)
630Q2=-((1-R1)^2-E7*E7*R2)*(1-A6)
635Q8=-((1-R1)^2-E8*E8*R2)*(1-A8)
640Q9=-((1-R1)^2-E9*E9*R2)*(1-A9)
645Q3=((1+R1)^2-E7*E7*R2)*COS(B)
650D3=((1+R1)^2-E8*E8*R2)*COS(B3)
655D4=((1+R1)^2-E9*E9*R2)*COS(B4)
660H6=Q6*TAN(B3/2)
665H7=Q7*TAN(B4/2)
670 Q4=-2*E7*R1*(1+R1)*SIN(B)
675D5=-2*E8*R1*(1+R1)*SIN(B3)
680D6=-2*E9*R1*(1+R1)*SIN(B4)
685Q5=Q2+Q3+Q4
690D7=Q8+D3+D5
695D8=Q9+D4+D6
700H3=((1+R1)^2-E7*E7*R2)*SIN(B)
705J1=((1+R1)^2-E8*E8*R2)*SIN(B3)
710J2=((1+R1)^2-E9*E9*R2)*SIN(B4)
715H2=2*E7*R1*(1+R1)*COS(B)
720H8=2*E8*R1*(1+R1)*COS(B3)
725H9=2*E9*R1*(1+R1)*COS(B4)
730H4=2*E7*R1*(R1-1)*(1-A6)
735J3=2*E8*R1*(R1-1)*(1-A8)
740J4=2*E9*R1*(R1-1)*(1-A9)
745H5=H2+H3+H4
750J5=H8+J1+J3
755J6=H9+J2+J4
760M2=SQR(Q5^2+H5^2)
765D2=ATN(H5/Q5)
770T1=D1+180/P
775J7=(Q6*D7+H6*J5)/(D7*D7+J5*J5)
780J8=(Q7*D8+H7*J6)/(D8*D8+J6*J6)
785K3=(H6*D7-Q6*J5)/(D7*D7+J5*J5)
790K4=(H7*D8-Q7*J6)/(D8*D8+J6*J6)
795T2=D2+180/P
800K5=ATN(K3/J7)
805K6=ATN(K4/J8)
810S=M1/M2
811T5=(20*LOG(1/S))/C9
815IF (K6*K5)^2<1 THEN 840
820IF K6*K5<0 THEN 830
825IF K6*K5>0 THEN 840
830K9=(K5*P*K6)/(4*P*M3)
835IF K6*K5<0 THEN 845
840K9=(K5-K6)/(4*P*M3)
841IF K5>K6 THEN 845
842K9=-K9
845G1=(Q1*Q5+H1*H5)/(Q5*Q5+H5*H5)
850G2=(H1*Q5-Q1*H5)/(Q5*Q5+H5*H5)
855G3=ATN(G2/G1)
860T3=G3*180/P
865IF G1<0 THEN 880
870PRINT F,T5,S,T3,K9
875IF G1>0 THEN 885
880PRINT F,T5,S,T3+180,K9
885NEXT F
999END

```

Appendix ICS11

ICS11 09:35 06/07/74

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1REM
2REM INPUT DATA REQUIRED:
3REM
4REM
5REM FOR COAXIAL SYSTEM INTO WHICH 2-PORT IS INSERTED:
6REM COAXIAL SYSTEM DESIGNATOR.....LINE 250
7REM ODIC (INCHES).....LINE 205 A1
8REM IDOC (INCHES).....LINE 215 B1
9REM FOR INCREASED ODIC 2-PORT STANDARD:
10REM DDIC (INCHES).....LINE 210 A2
11REM IDOC (INCHES).....LINE 220 B2
12REM LENGTH (INCHES).....LINE 225 L
13REM TC RESISTIVITY (OHM-CM).....LINE 230 P1
14REM DC RESISTIVITY (OHM-CM).....LINE 235 P2
15REM DISCONTINUITY CAPACITANCE DIVIDED BY CIRCUMFER-
16REM ENCE OF OC (FARADS/CM).....LINE 240 C1
17REM (NOTE THAT C1 IS ASSUMED INDEPENDENT OF
18REM FREQUENCY AND IS NOT CALCULATED BY THIS PRO-
19REM GRAM BUT MUST BE OBTAINED BY OTHER MEANS)
20REM RELATIVE PERMITTIVITY OF AIR.....LINE 200 E
21REM FREQUENCIES (GHZ).....LINE 329 F
22REM
23REM CALCULATED PARAMETERS:
24REM
25REM TEM MODE Z0 OF COAXIAL SYSTEM (OHMS).....LINE 305 Z1
26REM TEM MODE Z0 OF 2-PORT (OHMS).....LINE 310 Z2
27REM DISCONTINUITY CAPACITANCE (FARADS).....LINE 360 C2
28REM DISCONTINUITY SUSCEPTANCE/Y02.....LINE 370 E7
29REM (NOTE THAT Y02=1/Z02)
30REM GUIDE WAVELENGTH (INCHES).....LINE 330 W
31REM TC SKIN DEPTH (CM).....LINE 335 K1
32REM DC SKIN DEPTH (CM).....LINE 340 K2
33REM ATTENUATION CONSTANT OF 2-PORT(N/CM).....LINE 345 A
34REM (ATTEN. CONST.)*(LENGTH)---(DB).....LINE 355 A7
35REM RETURN LOSS (DB) CORRESPONDING TO S11.....LINE 481 T5
36REM MAGNITUDE OF S11.....LINE 480 S
37REM ARGUMENT OF S11 (DEGREES).....LINE 500 T3
38REM (NOTE THAT IF G1<0 THEN T3+180)
39REM
40REM P=3.14159265
41REM C=2.997925*10^10
42REM N=0.68599
43REM I15N1=2.54
44REM N3=.5/P
45REM Z0E=1.00064
46REM Z0SA1=.24425
47REM Z10 A2=.2651
48REM Z15B1=.5625
49REM Z20B2=B1
50REM Z25 L=11.911
51REM Z30P1=R/10^6
52REM Z35P2=P1
53REM Z40 C1=.569295/10^15
54REM Z45V=C/(N1*SGR(E))
55REM Z46Z1=59.9392*LOG(R1/A1)
56REM Z47Z2=59.9392*LOG(B2/A2)
57REM Z48C9=2.302585093
58REM Z50PRINT"FOR 9/16 INCH (14 MM) COAXIAL SYSTEM:"
59REM Z51PRINT" ODIC "A1;"INCHES"
60REM Z52PRINT" IDOC "B1;"INCHES"
61REM Z53PRINT" TEM-MODE CHARACTERISTIC IMPEDANCE "Z1;"OHMS"
62REM
63REM Z54PRINT
64REM Z55PRINT"FOR 2-PORT:"
65REM Z56PRINT" DOIC "A2;"INCHES"
66REM Z57PRINT" IDOC "B2;"INCHES"
67REM Z58PRINT" LENGTH "L;"INCHES"
68REM Z59PRINT" TEM-MODE CHARACTERISTIC IMPEDANCE "Z1;"OHMS"
69REM Z60PRINT" DISCONTINUITY CAPACITANCE "C1*P*B1*N1;"FARAOS"
70REM Z61PRINT" RELATIVE PERMITTIVITY OF AIR "E
71REM Z62PRINT" TC RESISTIVITY "P1;"OHM-CM."
72REM Z63PRINT" DC RESISTIVITY "P2;"OHM-CM."
73REM Z64PRINT
74REM Z15K1=Z1/Z2
75REM Z20R2=R1+Z2
76REM Z23P1NT
77REM Z24PK1NT"FREQUENCY","RETURN LOSS"," "ARG(S11)"
78REM Z25PRINT" GHZ "OECBELS","MAG(S11)","DEGREES"
79REM Z26PRINT
80REM Z29 FOR F=.1 TO .5 STEP .01
81REM Z30 W=V/(F*10^9)
82REM Z33K1=N3*SGR(P1/F)
83REM Z34K2=N3*SGR(P2/F)
84REM Z345A=2*P*F*((K1/A2)+(K2/B2))/(N1*Z2)
85REM Z350 A6=2*A*L*N1
86REM Z355A7=A6*N/2
87REM Z360C2=P*B1*N1*C1
88REM Z365 B3=2*P*F*C2*10^9
89REM Z370 E7=Z2*B3
90REM Z375 B=4*P*L/W
91REM Z380S5=SIN(B)
92REM Z385C5=COS(F)
93REM Z390A9=1-A6
94REM Z395C6=E7*E7*R2
95REM Z400R3=(1-R2+C6)*(1-A9*C5)
96REM Z405R4=-2*E7*R2*A9*S5
97REM Z410R5=R3+R4
98REM Z415I1=-2*E7*R2*(1+A9*C5)
99REM Z420I2=(1-R2+C6)*A9*S5
100REM Z425I3=I1+I2
101REM Z430M1=SGR(R5+I3+I2)
102REM Z435K6=(1+R1)+I2-C6
103REM Z440R7=(1+R1)+I2-(E7*R1)+I2*C5
104REM Z445R8=(2*E7*R1)*(1+R1)*S5
105REM Z450R9=R6-A9*(R7+R8)
106REM Z455I4=(2*E7*R1)*(1+R1)
107REM Z460I5=R7*TAN(R)
108REM Z465I6=-2*E7*R1*(1+R1)*C5
109REM Z470I7=I4*(1-A6)*(I5+I6)
110REM Z475M2=SGR(R9+I2+I7+I2)
111REM Z480S=M1/M2
112REM Z481T5=(20*LOG(1/S))/C9
113REM Z485G1=(R5+R9+I3+I7)/(R9+R9+I7+I7)
114REM Z490G2=(I3+R9-R5+I7)/(R9+R9+I7+I7)
115REM Z495G3=ATN(G2/G1)
116REM Z500T3=G3*180/P
117REM Z505IF G1<0 THEN 520
118REM Z510PRINT F,T5,S,T3
119REM Z515IF G1>0 THEN 525
120REM Z520PRINT F,T5,S,T3+180
121REM Z525NEXT F
122REM Z999END

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Appendix ICS21

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2-PM INPUT DATA REQUIRED:

4-PM FOR COAXIAL SYSTEM INTO WHICH 2-PORT IS INSERTED:
 6-PM COAXIAL SYSTEM DESIGNATOR.....LINE 296
 7-PM ODIC (INCHES).....LINE 135 A1
 9-PM IDOC (INCHES).....LINE 145 B1
 10-PM FOR INCREASED ODIC 2-PORT STANDARD:
 12-PM ODIC (INCHES).....LINE 140 A2
 14-PM IDOC (INCHES).....LINE 150 B2
 16-PM LENGTH (INCHES).....LINE 155 L
 18-PM IC RESISTIVITY (OHM-CM.).....LINE 160 P1
 20-PM OC RESISTIVITY (OHM-CM.).....LINE 165 P2
 22-PM DISCONTINUITY CAPACITANCE DIVIDED BY CIRCUMFER-
 24-PM ENCE OF OC (FARADS/CM.).....LINE 170 C5
 26-PM (NOTE THAT C5 IS ASSUMED INDEPENDENT OF FRE-
 28-PM QUENCY AND IS NOT CALCULATED BY THIS PRO-
 30-PM GRAM BUT MUST BE OBTAINED BY OTHER MEANS)
 32-PM RELATIVE PERMITTIVITY OF AIR.....LINE 130 E
 34-PM FREQUENCIES (GHZ).....LINE 400 F
 36-PM
 38-PM DELTA F FOR GROUP DELAY CALCULATION...LINE 205 M3

40-PM
 42-PM CALCULATED PARAMETERS:

44-PM TEM MODE 20 OF COAXIAL SYSTEM (OHMS).....LINE 180 Z1
 46-PM TEM MODE 20 OF 2-PORT (OHMS).....LINE 185 Z2
 48-PM DISCONTINUITY CAPACITANCE (FARADS).....LINE 190 C2
 50-PM DISCONTINUITY SUSCEPTANCE/Y02.....LINE 400 E7
 52-PM (NOTE THAT Y02=1/Z02)
 54-PM GUIDE WAVELENGTH (INCHES).....LINE 420 W
 56-PM IC SKIN DEPTH (CM.).....LINE 435 K1
 58-PM OC SKIN DEPTH (CM.).....LINE 440 K2
 60-PM ATTENUATION OF 2-PORT (DECIBELS).....LINE 811 T5
 62-PM ATTENUATION CONSTANT OF 2-PORT (N/CM).....LINE 445 A
 64-PM (ATTEN. CONST.)*(LENGTH)---(DB).....LINE 460 A7
 66-PM MAGNITUDE OF S21.....LINE 810 S
 68-PM ARGUMENT OF S21 (DEGREES).....LINE 860 T3
 70-PM (NOTE THAT IF G1<0 THEN T3=180)
 72-PM GROUP DELAY (NANOSECONDS).....LINE 830 K9
 74-PM (NOTE THAT IF K6*K5>0 THEN LINE LINE 840)

100P=3.14159265
 105C=2.997925*10*10
 110N=8.68589
 115N1=2.54
 125N3=.5/P
 130E=1.00064
 135A1=.24425
 140 A2=.2651
 145B1=.5625
 150 B2=B1
 155L=30/N1
 160 P1=9/10*6
 165 P2=P1
 170 C5=.569295/10*15
 175V=C/(N1*SQR(E))
 180Z1=59.9392*LOG(P1/A1)
 185Z2=59.9392*LOG(P2/A2)
 190 C2=P*P1*N1*C5
 195R1=Z1/Z2
 200R2=R1*2
 205M3=.005
 210C9=2.302585093
 296PRINT"FOR 9/16 INCH (14 MM) COAXIAL SYSTEM:"
 300 PRINT" ODIC "A1" INCHES"
 305PRINT" IDOC "B1" INCHES"
 310 PRINT" TEM-MODE CHARACTERISTIC IMPEDANCE",Z1,"OHMS"
 315PRINT
 318PRINT"FOR 2-PORT:"
 319 PRINT" "A2" INCHES"
 320PRINT" IDOC "B2" INCHES"
 325PRINT" LENGTH "L" INCHES"
 330 PRINT" TEM-MODE CHARACTERISTIC IMPEDANCE",Z2,"OHMS"
 335PRINT" DISCONTINUITY CAPACITANCE "C5*P*B1*N1,"FARADS"
 340PRINT" RELATIVE PERMITTIVITY OF AIR "E
 345PRINT" IC RESISTIVITY "P1,"OHM-CM."
 350PRINT" OC RESISTIVITY "P2,"OHM-CM."
 355PRINT
 360 PRINT"DELTA F FOR CALCULATION OF GROUP DELAY",M3,"GHZ"
 365PRINT
 366PRINT
 370PRINT"FREQUENCY","ATTENUATION"," "ARG(S21)","GROUP DELAY"
 375PRINT" GHZ ","DECIBELS","MAG(S21)","DEGREES","NANOSECONDS"

330PRINT
 400FOR F=.1 TO .5 STEP .01
 410F1=F*M3
 415F2=F*M3
 420V=V/(F*10*10)
 425W1=W*F/F1
 430V2=W*F/F2
 435K1=N3*SQR(P1/F)
 440C2=N3*SQR(P2/F)
 445 A=2*P*F*((K1/A2)+(K2/F2))/(N1*72)
 450A6=2*A*L*N1
 460A7=A6*N/2
 465AR=A6*SQR(F1/F)
 470AR=A6*SQR(F2/F)
 475R5=2*P*F*C2*10*10
 480E7=Z2*R5
 485ER=E7*(F1/F)
 490E9=E7*(F2/F)
 495R=4*P*L/W
 500R3=E*W/W1
 505R4=R*W/W2
 600Q1=4*R1*(1-A6/2)*COS(R/2)
 605C6=4*R1*(1-A7/2)*COS(B3/2)
 610P7=4*R1*(1-A9/2)*COS(B4/2)
 615H1=4*R1*(1-A6/2)*SIN(B/2)
 620M1=SQR(C1*2+H1*2)
 625D1=ATN(H1/O1)
 630C2=((1-R1)*2-E7*E7*R2)*(1-A6)
 635O9=((1-R1)*2-ER*ER*R2)*(1-AR)
 640O9=((1-R1)*2-E9*E9*R2)*(1-A9)
 645O3=((1+R1)*2-E7*E7*R2)*COS(B)
 650D3=((1+R1)*2-ER*ER*R2)*COS(B3)
 655D4=((1+R1)*2-E9*E9*R2)*COS(B4)
 660H6=O6*TAN(B3/2)
 665H7=O7*TAN(F4/2)
 670 Q4=2*E7*R1*(1+R1)*SIN(B)
 675D5=2*ER*R1*(1+R1)*SIN(B3)
 680D6=2*E9*R1*(1+R1)*SIN(B4)
 685O5=O2+C3+Q4
 690D7=O8+D3+D5
 695D9=O9+D4+D6
 700H3=((1+R1)*2-E7*E7*R2)*SIN(B)
 705J1=((1+R1)*2-ER*ER*R2)*SIN(B3)
 710J2=((1+R1)*2-E9*E9*R2)*SIN(B4)
 715H2=2*E7*R1*(1+R1)*COS(B)
 720H8=2*ER*R1*(1+R1)*COS(B3)
 725H9=2*E9*R1*(1+R1)*COS(B4)
 730H4=2*E7*R1*(R1-1)*(1-A6)
 735J3=2*ER*R1*(R1-1)*(1-AR)
 740J4=2*E9*R1*(R1-1)*(1-A9)
 745H5=H2+H3+H4
 750J5=H8+J1+J3
 755J6=H9+J2+J4
 760M2=SQR(O5*2+H5*2)
 765D2=ATN(H5/O5)
 770T1=D1*180/P
 775J7=(O6*D7+H6*J5)/(D7*D7+J5*J5)
 780J8=(O7*D8+H7*J6)/(D8*D8+J6*J6)
 785K3=(H6*D7-O6*J5)/(D7*D7+J5*J5)
 790K4=(H7*D8-O7*J6)/(D8*D8+J6*J6)
 795T2=D2*180/P
 800K5=ATN(K3/J7)
 805K6=ATN(K4/J8)
 810S=M1/M2
 811T5=(20*LOG(1/S))/C9
 815IF (K6*K5)>2<1 THEN R30
 820IF K6*K5<0 THEN R30
 825IF K6*K5>0 THEN R40
 830K9=(K5*P-K6)/(4*P*M3)
 835IF K6*K5<0 THEN R45
 840K9=(K5-K6)/(4*P*M3)
 841IF K5>K6 THEN R45
 842K9=K9
 845I=(O1*O5+H1*H5)/(O5*O5+H5*H5)
 850G2=(H1*O5-O1*H5)/(O5*O5+H5*H5)
 855G3=ATN(G2/G1)
 860T3=G3*180/P
 865IF G1<0 THEN R80
 870PRINT F,T5,S,T3,K9
 875IF G1>0 THEN R85
 880PRINT F,T5,S,T3*180,K9
 885NEXT F
 999END

Appendix WS11

WS11 14:57 06/04/74

```

2REM INPUT DATA REQUIRED:
4REM
6REM FDR WAVEGUIDE SYSTEM:
7REM WAVEGUIDE DESIGNATOR.....LINE 200
9REM INTERNAL WIDTH (INCHES).....LINE 75 A1
10REM INTERNAL HEIGHT (INCHES).....LINE 80 B1
12REM
14REM FDR REDUCED HEIGHT 2-PDRT:
16REM INTERNAL WIDTH (INCHES).....LINE 82 A2
18REM INTERNAL HEIGHT (INCHES).....LINE 85 B2
20REM LENGTH (INCHES).....LINE 87 L
22REM RESISTIVITY (OHM-CM).....LINE 90 P1
24REM RELATIVE PERMITTIVITY OF AIR.....LINE 70 E
26REM FREQUENCIES (GHZ).....LINE 320 F
28REM
30REM
32REM CALCULATED PARAMETERS:
34REM
36REM GUIDE WAVELENGTH (INCHES).....LINE 580 W
38REM NORMALIZED (TO Y0 OF 2-PORT) SUSCEPTANCE
40REM DF DISCONTINUITY.....LINE 685 E7
42REM NORMALIZED (TO Y0 OF WG SYSTEM) SUSCEPTANCE
44REM DIVIDED BY RATIO OF INTERNAL HEIGHT OF WG SYSTEM
46REM TO GUIDE WAVELENGTH.....LINE 690 ER
48REM SKIN DEPTH (CM).....LINE 325 K1
50REM ATTENUATION CONSTANT OF 2-PDRT (DB/FT).....LINE 600 A5
52REM ATTENUATION OF 2-PDRT (DECIBELS).....LINE 607 A7
53REM RETURN LOSS (DB) CORRESPONDING TO S11 .....LINE 506 T5
54REM MAGNITUDE OF S11 .....LINE 505 S
56REM ARGUMENT OF S11 (DEGREES).....LINE 525 T3
58REM (NOTE THAT IF G1<0 THEN T3+180)
60REMM
64 P=3.14159265
65 C=2.997925*10+10
70 E=1.00064
75 A1=0.9
80 B1=0.4
82 A2=0.9
85 B2=0.0918
87 L=.4052
90 P1=8.5/10+6
95 N=2*4.342945
100 N1=2.54
105 V=C/SQR(E)
110 V1=V/N1
115 N2=5.963
120 C9=2.302585093
160 N3=.5/P
200 PRINT "FDR WR-90 (R-100) WAVEGUIDE SYSTEM:"
205 PRINT "INTERNAL WIDTH "A1:"INCHES"
210 PRINT "INTERNAL HEIGHT "B1:"INCHES"
215 PRINT
220 PRINT "FDR 2-PDRT:"
225 PRINT "INTERNAL WIDTH "A2:"INCHES"
230 PRINT "INTERNAL HEIGHT "B2:"INCHES"
235 PRINT "LENGTH "L:"INCHES"
240 PRINT "RESISTIVITY "P1:"OHM-CM."
245 PRINT "RELATIVE PERMITTIVITY OF AIR "E
250 V=C/(N1*SQR(E))
255 R1=B1/B2
260 R2=R1+2
295 PRINT
300 PRINT
305 PRINT "FREQUENCY","RETURN LOSS","ARG(S11)"
310 PRINT "GHZ ","DECIBELS","MAG(S11)","DEGREES"

315 PRINT
320 FDR F=R TO 13 STEP .1
325 K1=N3*SQR(P1/F)
405 GDSUB 560
410
420 B=4*P*L/W
425 R3=(1-R2*(E7+2)*R2)*(1-(1-A6)*CDS(B))
430 R4=-2*E7*R2*(1-A6)*SIN(B)
435 R5=R3+R4
440 I1=-2*E7*R2*(1-(1-A6)*CDS(B))
445 I2=(1-R2+E7*R2)*(1-A6)*SIN(B)
450 I3=I1+I2
455 M1=SDR(R5+2*I3+2)
460 R6=(1+R1)*2-(E7+2)*R2
465 R7=((1-R1)*2-(E7*R1)*2)*CDS(B)
470 R8=(2*E7*R1)*(1-R1)*SIN(B)
475 R9=R6-(1-A6)*(R7+R8)
480 I4=(2*E7*R1)*(1+R1)
485 I5=((1-R1)*2-(E7*R1)*2)*SIN(B)
490 I6=-2*E7*R1*(1-R1)*CDS(B)
495 I7=I4+(1-A6)*(I5+I6)
500 M2=SDR(R9+2*I7+2)
505 S=M1/M2
506 T5=(20*LDG(1/S))/C9
510 G1=(R5*R9+I3*I7)/(R9*R9+I7*I7)
515 G2=(I3*R9-R5*I7)/(R9*R9+I7*I7)
520 G3=ATN(G2/G1)
525 T3=G3+180/P
530 IF G1<0 THEN 545
535 PRINT F,T5,S,T3
540 IF G1>0 THEN 550
545 PRINT F,T5,S,T3+180
550 NEXT F
555 END
560 L1=SQR(E)
565 L2=C/(10+9)
570 L3=(N1*F*L1/L2)+2
575 L4=(1/(2*A1))+2
580 W=L1/SQR(L3-L4)
585 A2=1/L3
590 A3=SQR(SQR(A2))
595 A4=N2*SQR(P1)
600 A5=((A4/A3)*((1/B2)+A2/(2*A1+3)))/SQR(1-A2/((2*A1)+2))
605 A6=(L/(6*N))*A5
607 A7=A6*N
610 D1=B2/B1
615 D2=(4*D1/(1-D1+2))+2
620 D3=((1+D1)/(1-D1))+2/D1
625 D4=(1+SQR(1-(B2/W)+2))/((1-SQR(1-(B2/W)+2)))
630 D5=D3*D4*(3*(D1)+2)/(1-(D1)+2)
635 D6=D3*((D1)+2)
640 D7=(1+SQR(1-(B1/W)+2))/(1-SQR(1-(B1/W)+2))
645 D8=D6*D7-(1+3*(D1+2))/(1-(D1)+2)
650 D9=((1-D1+2)/(4*D1))*((1+D1)/(1-D1))+((1/2)*(D1+1/D1))
655 E1=LDG(D9)
660 E2=2*(D8+D5+2*D2)/(D8+D5+D2+2)
665 E3=((B1/(4*W))+2)*((1-D1)/(1+D1))+4*D1
670 E4=((5*(D1+2))-1)/(1-D1+2)
675 E5=(4*(D1+2)+D2)/(3*D8)
680 E6=E3*(E4+E5)+2
685 E7=2*(E1+E2+E6)*(B2/W)
690 E7=1.04*E7
690 E8=E7*W/B2
695 RETURN

```

```

10REM INPUT DATA:
12REM
13REM WAVEGUIDE DESIGNATOR.....LINE 200
14REM FDR WAVEGUIDE SYSTEM:
16REM INTERNAL WIDTH (INCHES).....LINE 100 A1
18REM INTERNAL HEIGHT (INCHES).....LINE 105 B1
20REM
22REM FDR 2-PORT:
24REM INTERNAL WIDTH (INCHES).....LINE 110 A2
26REM INTERNAL HEIGHT (INCHES).....LINE 115 B2
28REM LENGTH (INCHES).....LINE 120 L
30REM RESISTIVITY (OHM-CM).....LINE 125 P1
32REM RELATIVE PERMITTIVITY OF AIR .....LINE 130 E
34REM
36REM FREQUENCIES (GHZ) .....LINE 300 F
38REM DELTA F FDR CALCULATION OF GROUP DELAY.....LINE 135 D
40REM
42REM CALCULATED PARAMETERS:
44REM
46REM MAGNITUDE OF S21.....LINE 395 S
48REM ARGUMENT OF S21 (DEGREES).....LINE 415 T3
50REM GRUPO DELAY (NANOSECONDS).....LINE 475 T3*100
52REM ALSO LINE 435 K9
54REM ALSO LINE 445 K9
56REM ALSO LINE 455 -K9
58REM GUIDE WAVELENGTH (INCHES).....LINE 1010 W
60REM SKIN DEPTH (CENTIMETERS).....LINE 480 K1
62REM ATTENUATION OF 2-PORT (DECIBELS).....LINE 396 T5
64REM ATTENUATION CONSTANT OF 2-PORT (DB/FT).....LINE 1030 A5
66REM ATTENUATION CONSTANT*LENGTH (DECIBELS).....LINE 1125 A7
68REM NORMALIZED (TO Y0 OF 2-PORT) SUSCEPTANCE
70REM OF DISCONTINUITY.....LINE 1115 E7
72REM NORMALIZED (TO Y0 OF WG SYSTEM) SUSCEPTANCE
74REM OF DISCONTINUITY DIVIDED BY KATID B1/W .....LINE 1120 E8
76REM
78REM
80REM
100A1=0.9
105B1=0.4
110A2=0.9
115B2=0.0918
120L=0.4052
125 P1=9.5/10+6
130E=1.00064
135D=0.05
140P=3.14159265
145N=9.68589
150N1=2.54
155N2=5.963
160N3=0.5/P
165C=2.997925*10+10
170R1=B1/B2
175R2=R1+2
180L1=SDR(E)
185L2=C/10+9
190C9=2.302585093
200PRINT "FDR WR-90 (R-100) WAVEGUIDE SYSTEM:"
205PRINT "INTERNAL WIDTH", "A1", "INCHES"
210PRINT "INTERNAL HEIGHT", "B1", "INCHES"
215PRINT
220PRINT "FDR 2-PORT:"
225PRINT "INTERNAL WIDTH", "A2", "INCHES"
230PRINT "INTERNAL HEIGHT", "B2", "INCHES"
235PRINT "LENGTH", "L", "INCHES"
240PRINT "RESISTIVITY", "P1", "OHM-CM."
245PRINT "RELATIVE PERMITTIVITY OF AIR", "E"
250PRINT
255PRINT "DELTA F FDR CALCULATION OF GROUP DELAY", "D", "GHZ"
260PRINT
265PRINT
270PRINT "FREQUENCY", "ATTENUATION", "ARG(S21)", "GROUP DELAY"
275PRINT "GHZ", "DECIBELS", "DEGREES", "NANSECONDS"
280PRINT
300FDR=F TO 13 STEP 0.1
301F1=F-D
302F2=F+D
305GDSUB 1000
310B=4*P*L/W
311B3=4*P*L/W1
312P4=4*P*L/W2
315D1=4*R1*(1-A6/2)*CD5(E/2)
316D6=4*R1*(1-A8/2)*CD5(B3/2)
317D7=4*R1*(1-A9/2)*CD5(E4/2)
320H1=4*R1*(1-A6/2)*SINC(E/2)
321H6=4*R1*(1-A8/2)*SINC(B3/2)
322H7=4*R1*(1-A9/2)*SINC(E4/2)
325M1=SDR(C1+2*H1+2)
330M3=ATN(H1/C1)
335D2=-(C1-R1)+2-E7*E7*R2*(1-A6)
336D9=-(C1-R1)+2-F3*F3*R2*(1-A8)
337D9=-(C1-R1)+2-F4*F4*R2*(1-A9)
340Q3=(C1+R1)+2-E7*E7*R2*(C5(B)
341R3=(C1+R1)+2-F3*F3*R2*(C5(E)
342R4=(C1+R1)+2-F4*F4*R2*(C5(E4)
345D4=-2*E7*R1*(C1+R1)*SINC(E)
346R5=-2*F3*R1*(C1+R1)*SINC(B)
347R6=-2*F4*R1*(C1+R1)*SINC(E4)
350D5=C2+Q3+Q4
351 R7=D9+R3+R5
352R9=Q9+R4+R6
355H3=C3*TAN(B)
356J1=R3*TAN(E)
357J2=R4*TAN(E4)
360H2=-C4/TAN(B)
361H8=-R5/TAN(B)
362H9=-R6/TAN(B4)
365H4=2*E7*R1*(C1-1)*(1-A6)
366J3=2*F3*R1*(C1-1)*(1-A8)
367J4=2*F4*R1*(C1-1)*(1-A9)
370H5=H2+H3+H4
371J5=H8+J1+J3
372J6=H9+J2+J4
375M2=SDR(Q5+2*H5+2)
380M4=ATN(H5/Q5)
385T1=M3+180/P
390T2=M4+180/P
395S=M1/M2
396T5=(20*LDG(1/S))/C9
400G1=(Q1+Q5+H1*H5)/(D5+2*H5+2)
401J7=(C6+R7+H6*J5)/(R7+2*J5+2)
402J8=(Q7+R8+H7*J6)/(R8+2*J6+2)
405G2=(H1+Q5-Q1*H5)/(D5+2*H5+2)
406K3=(H6+R7-D6*J5)/(R7+2*J5+2)
407K4=(H7+R8-Q7*J6)/(R8+2*J6+2)
410G3=ATN(G2/G1)
411K5=ATN(K3/J7)
412K6=ATN(K4/J8)
415T3=G3+180/P
420I F (K6*K5)+2 < 1 THEN 445
425I F K6*K5 < 0 THEN 435
430I F K6*K5 > 0 THEN 445
435K9=(K5+P-K6)/(4*P+D)
440I F K6*K5 < 0 THEN 460
445K9=(K5-K6)/(4*P+D)
450I F K5>K6 THEN 460
455K9=-K9
460I F G1 < 0 THEN 475
465PRINT F, T5, S, T3, K9
470I F G1 > 0 THEN 480
475PRINT F, T5, S, T3+180, K9
480K1=N3*SDR(P1/F)
485NEXT F
999END
1000L3=(N1*F*L1/L2)+2
1001L5=(N1*F*L1/L2)+2
1002L6=(N1*F2*L1/L2)+2
1005L4=(1/(2*A1))+2
1010W=1/SDR(L3-L4)
1011W1=1/SDR(L5-L4)
1012W2=1/SDR(L6-L4)
1015M5=1/L3
1016M6=1/L5
1017M7=1/L6
1020A3=SDR(SQR(M5))
1021S1=SDR(SQR(M6))
1022S2=SDR(SQR(M7))
1025A4=N2*SDR(P1)
1030A5=(A4/A3)*((1/B2)+M5/(2*A1+3))/SDR(1-M5/((2*A1)+2))
1031S5=(A4/S1)*((1/B2)+M6/(2*A1+3))/SDR(1-M6/((2*A1)+2))
1032S6=(A4/S2)*((1/B2)+M7/(2*A1+3))/SDR(1-M7/((2*A1)+2))
1035A6=(L/(6*N))*A5
1036A8=(L/(6*N))*S5
1037A9=(L/(6*N))*S6
1040D1=B2/B1
1045D2=(4*D1/(1-D1+2))+2
1050D3=(1+D1)/(1-D1+2)
1055D4=(1+SDR(1-(B2/W)+2))/(1+SDR(1-(B2/W)+2))
1056S7=(1+SDR(1-(B2/W1)+2))/(1+SDR(1-(B2/W1)+2))
1057S8=(1+SDR(1-(B2/W2)+2))/(1+SDR(1-(B2/W2)+2))
1060D5=D3*D4*(3+D1+2)/(1-D1+2)
1061P3=D3*S7*(3+D1+2)/(1-D1+2)
1062P4=D3*S8*(3+D1+2)/(1-D1+2)
1065D6=D3*(C1+2)
1070D7=(1+SDR(1-(B1/W)+2))/(1+SDR(1-(B1/W)+2))
1071P7=(1+SDR(1-(B1/W1)+2))/(1+SDR(1-(B1/W1)+2))
1072P8=(1+SDR(1-(B1/W2)+2))/(1+SDR(1-(B1/W2)+2))
1075D8=D6*D7*(1+3*(C1+2))/(1-D1+2)
1076K7=D6*P7*(1+3*(C1+2))/(1-D1+2)
1077K8=D6*P8*(1+3*(C1+2))/(1-D1+2)
1080D9=(1-D1+2)/(4*D1+2)*(1+D1)/(1-D1+2)*(1/2)*(C1+1/D1)
1085E1=LDG(D9)
1090E2=2*(D8+D5+2*D2)/(D8+D5-D2+2)
1091B7=2*(K7+P3+2*D2)/(K7+P3-D2+2)
1092B8=2*(K8+P4+2*D2)/(K8+P4-D2+2)
1095E3=(B1/(4*W))+2*(C1-D1)/(1+D1+2)*(4*D1)
1096C1=(B1/(4*W1))+2*(C1-D1)/(1+D1+2)*(4*D1)
1097C2=(B1/(4*W2))+2*(C1-D1)/(1+D1+2)*(4*D1)
1100E4=(C5*(C1+2)-1)/(1-D1+2)
1105E5=(4*(C1+2)+D2)/(3*D8)
1106C5=(4*(C1+2)+D2)/(3*K7)
1107C6=(4*(C1+2)+D2)/(3*K8)
1110E6=E3*(E4+E5)+2
1111C7=C1*(E4+C5)+2
1112C8=C2*(E4+C6)+2
1115E7=2*(E1+E2+E6)*(B2/W)
1116F3=2*(E1+B7*C7)*(B2/W1)
1117F4=2*(E1+B8*C8)*(B2/W2)
1118 E7=1.04+E7
1119 F3=1.04+F3
1120E8=E7*W/B2
1121 F4=1.04+F4
1125A7=A6*N/2
1130RETURN

```

```

2REM      INPUT DATA:
4REM      MAG(S11).....LINE 160 S
6REM      COAXIAL LINE DESIGNATOR.....LINE 100
8REM      IDOC OF COAXIAL SYSTEM.....LINE 110 B1 (INCHES)
10REM     ODIC OF COAXIAL SYSTEM.....LINE 105 A1 (INCHES)
12REM
14REM     CALCULATED PARAMETERS:
16REM     RETURN LOSS.....LINE 200 R2 (DB)
18REM     VSWR.....LINE 165 R
19REM     TEM-MODE CHARACTERISTIC IMPEDANCE...LINE 175 Z2 (OHMS)
20REM     REDUCED IDOC OF 2-PORT.....LINE 180 B2 (INCHES)
22REM
80A1=.24425
85B1=.5625
90A2=.24425
95Z1=59.9392*LOG(B1/A1)
100PRINT"FOR 9/16-INCH (14 MM) COAXIAL SYSTEM:"
105PRINT"  ODIC                      ","A1","INCHES"
110PRINT"  IDOC                      ","B1","INCHES"
112 PRINT"  TEM-MODE CHARACTERISTIC IMPEDANCE","Z1","OHMS"
115PRINT
120PRINT"FOR 2-PORT:"
125PRINT"  ODIC                      ","A2","INCHES"
130PRINT
135PRINT
140PRINT"      ","RETURN","      ","CHARACTERISTIC","REDUCED"
145 PRINT"      ","LOSS ","      ","IMPEDANCE","IDOC"
150PRINT"MAG(S11)","DECI BELS","VSWR"," OHMS ","INCHES"
155PRINT
160 FOR S=0 TO 0.95 STEP 0.05
165R=(1+S)/(1-S)
170R1=SQR(R)
175 Z2=Z1/R1
180 B2=A2*EXP(Z2/59.9392)
185C1=2.302585093
190R2=0
195IF S=0 THEN 210
200R2=(20*LOG(1/S))/C1
205IF S>0 THEN 220
210PRINT S,"INFINITY",R,Z2,B2
215 IF S=0 THEN 225
220 PRINT S,R2,R,Z2,B2
225NEXT S
999END
READY
RUN

```

IDOC 09:40 06/04/74

FOR 9/16-INCH (14 MM) COAXIAL SYSTEM:

ODIC	.24425 INCHES
IDOC	.5625 INCHES
TEM-MODE CHARACTERISTIC IMPEDANCE	50.0012 OHMS

FOR 2-PORT:

ODIC	.24425 INCHES
------	---------------

MAG(S11)	RETURN LOSS DECIBELS	VSWR	CHARACTERISTIC IMPEDANCE OHMS	REDUCED IDOC INCHES
0	INFINITY	1	50.0012	.5625
.05	26.0206	1.10526	47.5606	.540056
.1	20.	1.22222	45.2273	.519441
.15	16.4782	1.35294	42.9874	.500384
.2	13.9794	1.5	40.8258	.48266
.25	12.0412	1.66667	38.7308	.466081
.3	10.4576	1.85714	36.6909	.450486
.35	9.11864	2.07692	34.6953	.435735
.4	7.9588	2.33333	32.7335	.421704
.45	6.93575	2.63636	30.7948	.408283
.5	6.0206	3.	28.8682	.395368
.55	5.19275	3.44444	26.9414	.382861
.6	4.43698	4.	25.0006	.370662
.65	3.74173	4.71429	23.0289	.358668
.7	3.09804	5.66667	21.0047	.346758
.75	2.49878	7.	18.8987	.334785
.8	1.9382	9.	16.6671	.32255
.85	1.41162	12.3333	14.2377	.309738
.9	.91515	19.	11.4711	.295767
.95	.445528	39.	8.00661	.279154

```

2REM      INPUT DATA:
4REM      MAG(S11).....LINE 160 S
6REM      COAXIAL LINE DESIGNATOR.....LINE 100
8REM      IDOC OF COAXIAL SYSTEM.....LINE 110 B1 (INCHES)
10REM     ODIC OF COAXIAL SYSTEM.....LINE 105 A1 (INCHES)
12REM
14REM     CALCULATED PARAMETERS:
16REM     RETURN LOSS.....LINE 200 R2 (DB)
18REM     VSWR.....LINE 165 R
19REM     TEM-MODE CHARACTERISTIC IMPEDANCE...LINE 175 Z2 (OHMS)
20REM     INCREASED ODIC OF 2-PORT.....LINE 180 A2 (INCHES)
22REM
80A1=.24425
85B1=.5625
90B2=.5625
95Z1=59.9392*LOG(B1/A1)
100PRINT"FOR 9/16-INCH (14 MM) COAXIAL SYSTEM:"
105PRINT"    ODIC                      ","A1","INCHES"
110PRINT"    IDOC                      ","B1","INCHES"
112 PRINT"    TEM-MODE CHARACTERISTIC IMPEDANCE","Z1","OHMS"
115PRINT
120PRINT"FOR 2-PORT:"
125 PRINT"    IDOC                      ","B2","INCHES"
130PRINT
135PRINT
140PRINT"    ","RETURN",""          ","CHARACTERISTIC","INCREASED"
145PRINT"    ","LOSS",""            ","IMPEDANCE","    ODIC"
150PRINT"MAG(S11)","DECIBELS","VSWR"," OHMS ","INCHES"
155PRINT
160 FOR S=0 TO 0.95 STEP 0.05
165R=(1+S)/(1-S)
170R1=SQR(R)
175 Z2=Z1/R1
180A2=B2/(EXP(Z2/59.9392))
185C1=2.302585093
190R2=0
195IF S=0 THEN 210
200R2=(20*LOG(1/S))/C1
205IF S>0 THEN 220
210 PRINT S,"INFINITY",R,Z2,A2
215 IF S=0 THEN 225
220PRINT S,R2,R,Z2,A2
225NEXT S
999END
READY
RUN

```

ODIC 09:47 06/04/74

```

FOR 9/16-INCH (14 MM) COAXIAL SYSTEM:
    ODIC                      .24425 INCHES
    IDOC                      .5625 INCHES
    TEM-MODE CHARACTERISTIC IMPEDANCE 50.0012 OHMS

FOR 2-PORT:
    IDOC                      .5625 INCHES

```

MAG(S11)	RETURN LOSS DECIBELS	VSWR	CHARACTERISTIC IMPEDANCE OHMS	INCREASED ODIC INCHES
0	INFINITY	1	50.0012	.24425
.05	26.0206	1.10526	47.5606	.2544
.1	20.	1.22222	45.2278	.264497
.15	16.4782	1.35294	42.9874	.27457
.2	13.9794	1.5	40.8258	.284653
.25	12.0412	1.66667	38.7308	.294778
.3	10.4576	1.85714	36.6909	.304983
.35	9.11864	2.07692	34.6953	.315308
.4	7.9588	2.33333	32.7335	.325799
.45	6.93575	2.63636	30.7948	.336508
.5	6.0206	3.	28.8682	.347501
.55	5.19275	3.44444	26.9414	.358853
.6	4.43698	4.	25.0006	.370662
.65	3.74173	4.71429	23.0289	.383058
.7	3.09804	5.66667	21.0047	.396215
.75	2.49878	7.	18.8987	.410384
.8	1.9382	9.	16.6671	.425951
.85	1.41162	12.3333	14.2377	.44357
.9	.91515	19.	11.4711	.464524
.95	.445528	39.	8.00661	.492164

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```

2REM      INPUT DATA:
4REM      MAG(S11).....LINE 150 S
6REM      WAVEGUIDE DESIGNATOR.....LINE 100
8REM      NOMINAL HEIGHT OF WG SYSTEM.....LINE 95 H1 (INCHES)
9REM      NOMINAL WIDTH OF WG SYSTEM.....LINE 90 W (INCHES)
10REM
12REM     CALCULATED PARAMETERS:
14REM     RETURN LOSS.....LINE 175 R2 (DB)
16REM     VSWR.....LINE 155 R
18REM     REDUCED HEIGHT OF 2-PORT.....LINE 165 H2 (INCHES)
20REM
90 W=.9
95 H1=.4
100PRINT"FOR WR-90 (R-100) WAVEGUIDE SYSTEM:"
105PRINT"  INTERNAL WIDTH          ",W,"INCHES"
110PRINT"  INTERNAL HEIGHT         ",H1,"INCHES"
115PRINT
120PRINT"FOR 2-PORT:"
125PRINT"  INTERNAL WIDTH          ",W,"INCHES"
130PRINT
135PRINT
140 PRINT"      ","RETURN","      ","REDUCED"
142 PRINT"      ","LOSS  ","      ","HEIGHT"
144 PRINT"MAG(S11)","DECIBELS"," VSWR","INCHES"
145 PRINT
150 FOR S=0 TO 0.95 STEP 0.05
155R=(1+S)/(1-S)
160R1=SQR(R)
165 H2=H1/R1
170C1=2.302585093
172 R2=0
173 IF S=0 THEN 180
175 R2=(20*LOG(1/S))/C1
176 IF S>0 THEN 182
180 PRINT S,"INFINITY",R,H2
181 IF S=0 THEN 185
182 PRINT S,R2,R,H2
185NEXT S
999END
READY
RUN

```

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```

FOR WR-90 (R-100) WAVEGUIDE SYSTEM:
  INTERNAL WIDTH          .9 INCHES
  INTERNAL HEIGHT        .4 INCHES

```

```

FOR 2-PORT:
  INTERNAL WIDTH          .9 INCHES

```

MAG(S11)	RETURN LOSS DECIBELS	VSWR	REDUCED HEIGHT INCHES
0	INFINITY	1	.4
.05	26.0206	1.10526	.380476
.1	20.	1.22222	.361814
.15	16.4782	1.35294	.343891
.2	13.9794	1.5	.326599
.25	12.0412	1.66667	.309839
.3	10.4576	1.85714	.29352
.35	9.11864	2.07692	.277555
.4	7.9588	2.33333	.261861
.45	6.93575	2.63636	.246353
.5	6.0206	3.	.23094
.55	5.19275	3.44444	.215526
.6	4.43698	4.	.2
.65	3.74173	4.71429	.184226
.7	3.09804	5.66667	.168034
.75	2.49878	7.	.151186
.8	1.9382	9.	.133333
.85	1.41162	12.3333	.113899
.9	.91515	19.	.9.17663E-2
.95	.445528	39.	6.40513E-2

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